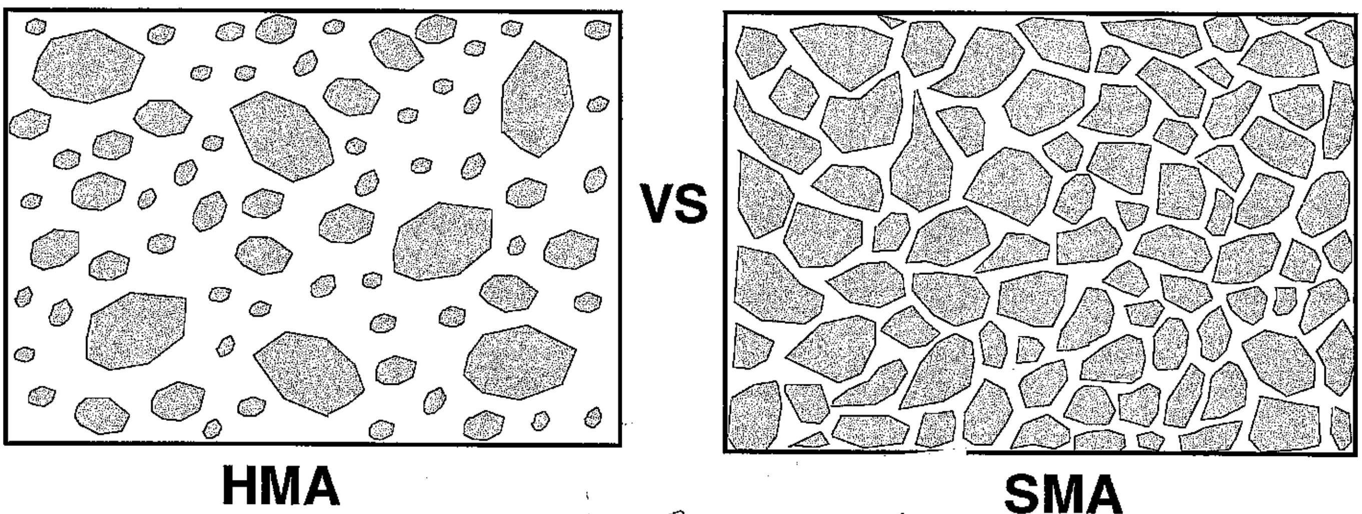
# Evaluation of Stone Matrix Asphalt (SMA)

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16. Abstract

Stability of conventional bituminous pavements is compromised and rutting rates are accelerated by continually increasing traffic volumes and heavy truck traffic. Stone Matrix Asphalt (SMA) was identified during the 1990 European Asphalt Study Tour (EAST) as a possible replacement mix for heavily trafficked pavements.

This report documents Illinois' experience with seven SMA projects. To determine what would best suit Illinois, the Illinois Department of Transportation (IDOT) investigated two different types of mixture gradations, three types of aggregates, and three types of modifiers. Findings to date indicate the three types of aggregates and modifiers performed adequately when designed to the coarser mixture gradation. The smaller SMA gradation type was not as successful. These mixtures generally were tender and flushed. SMA's were very sticky, especially the polymer-modified, and were difficult to remove from trucks and to work by hand. Mixing and laydown temperatures were found to be more critical than for dense-graded mixtures. Plant type (batch or drier-drum) did not affect mixture production. Costs were approximately 40% higher than for dense-graded mixtures. This cost is expected to decrease with experience.

The overall successes of the seven projects were variable. These projects will be monitored for performance. IDOT will consider SMA as an alternative to conventional dense-graded mixtures in areas of heavy and congested traffic, areas of heavy truck traffic, and areas where rutting has been a continual problem.

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# EVALUATION

# OF

# STONE MATRIX ASPHALT

## Final Report


BY

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BITUMINOUS FIELD ENGINEER


**October 1995**


Illinois Department of Transportation

Bureau of Materials and Physical Research

Springfield, Illinois

## Foreword

This report should be of interest to engineers involved in planning, design, inspection, and all other technical personnel concerned with asphalt paving mixtures.

## Notice/Disclaimer

This report is based on the results of Project IHR-538, the evaluation of Stone Matrix Asphalt in-situ. IHR-538 was sponsored by the Illinois Department of Transportation Division of Highways and the United States Department of Transportation Federal Highway Administration.

The contents of this report reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Illinois Department of Transportation or of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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## Executive Summary

Stability of present bituminous pavements have been compromised by heavy truck traffic which continues to increase, resulting in accelerated rutting rates. Stone Matrix Asphalt (SMA) was identified during the 1990 European Asphalt Study Tour (EAST) as a possible replacement mix for heavily trafficked pavements. The SMA mixture was designed initially to reduce pavement wear under studded tires, but a major benefit of the mixture was that it produced a mixture more resistant to rutting than dense-graded mixtures. This benefit is obtained through the emphasis of the stone-on-stone contact in the mixture.

Unlike typical dense-graded asphalt hot mixes currently used in this country, SMA is a gap-graded asphalt hot-mix. It contains an increased amount of coarse aggregate, filler, and asphalt cement; a modifier to prevent drain-down; and less of the mid-sized sand used in current asphalt concrete pavement mixes.

Another benefit of SMA mixtures is the mixture's durability potential is increased. This is caused by both the amount of asphalt cement (minimum of 6 percent by weight of mix) and the use of a modifier. The modifier helps the asphalt stick to the aggregate particles, thus producing thicker asphalt film thickness on the aggregate particles, resulting in a mixture that is impermeable to water. Therefore, SMA mixtures are very promising due to the effectiveness in preventing both rutting and shoving, and in increasing the mixture's durability potential at the same time.

The Illinois Department of Transportation (IDOT), in 1992, decided to try experimental SMA projects. IDOT was interested in studying the following variables to determine if SMA would be a good alternative mixture to IDOT's dense-graded mixture in certain applications: different gradation types, three different modifiers, different types of asphalt plants, constructability, cost, Illinois carbonate aggregates, and frictional properties of SMA's.

The Federal Highway Administration (FHWA) distributed model specifications for both designing and constructing SMA. Illinois followed the FHWA model specifications with one exception. Illinois investigated the feasibility of constructing SMA by utilizing two different gradation types. The first SMA mix was a "large SMA" mix gradation which required two coarse aggregates - a modified large-sized coarse aggregate (minus 3/4 inch and plus 3/8 inch) that when combined with a chip would meet the recommended FHWA gradation. The second SMA mix was a "small SMA" mix gradation which used only a chip (CA16 or CA13) in combination with a manufactured sand and would not meet the FHWA recommended gradation but would be more economical. One of IDOT's intents was to determine if the "small SMA" gradation would perform adequately when compared to the "large SMA" gradation or to IDOT's dense-graded mixtures. After evaluation of both types of SMA mixes, the "large SMA" mix gradation performed much better, or more like an SMA. The "large SMA" was structurally sound, very stout, and not tender like the "small SMA" mix type.

There was initial concern that the "large SMA" mix gradation would cost more than the "small SMA" mix gradation due to the modified large-sized coarse aggregate. However, only one "large SMA" project was significantly higher in cost due to the modified aggregate.

Three different types of modifiers were tried in the experimental projects to identify which modifier best suits Illinois, both in performance-related aspects and cost effectiveness. The introduction method of these different modifiers was evaluated for uniformity and consistency when producing the mixture. Both the cellulose fibers and polymer asphalt performed well with few problems. However, the project which used mineral fibers required twice as much fiber than cellulose; therefore, mixing times were increased significantly. There was no significant increase in cost related to the type of modifier used.

When utilizing polymer-modified asphalt as the modifier, SMA's are extremely sticky and difficult to remove from the trucks. They are also difficult to hand-work. This occurrence may cause construction problems and has not been resolved.

The type of plant, i.e., drier-drum or batch, did not cause any problems when producing SMA. However, plant modifications, particularly for introducing fibers and mineral filler, were common for all projects.

Mixing and laydown temperatures were found to be very critical to the constructability of SMA's. This is due to the gap-graded nature of the mixture and the type of modifier. If the mixture was produced too hot, drain-down would occur; if the laydown temperature was too low, obtaining densities was very difficult. However, the optimum mixing and laydown temperatures varied from project to project in order to meet each project's job-specific characteristics.

There was initial concern that Illinois' carbonate aggregates would not perform adequately due to SMA mixes having stone-on-stone contact. Europe utilized hard igneous and metamorphic aggregates for this reason. Illinois' carbonate aggregates did not seem to easily crush or break down in the SMA mixes. However, to prevent any potential problems, future SMA projects will require heavy static rollers operating in the breakdown position instead of vibratory rollers.

Frictional properties were also an initial concern due to the increased asphalt film thickness on the aggregate particles though the use of modifiers. Increased asphalt film thickness normally produces reduced frictional properties and slicker pavements. However, six months after construction the skid numbers were generally comparable to dense-graded mixtures which used the same aggregates.

In addition to the IDOT experimental SMA projects, IDOT provided technical assistance for a private project which placed a steel slag SMA mix at Levy's steel plant in Indiana. The project has numerous steel-tracked loaders and 150-ton trucks using it on a daily basis. The section is performing remarkably well. Indiana high-type dense-graded mixtures used prior to the SMA have all failed prematurely due to these loadings.

It is believed that SMA's may replace IDOT's higher type mixtures in certain applications. By no means will SMA replace dense-graded Class I mixtures. It should not be considered a "mixture to end all mixtures". However, SMA's may be used in areas of heavy truck traffic, areas of heavy and congested traffic, and areas where rutting has been a continual problem.

## Introduction

Stone Matrix Asphalt (SMA) is defined as a gap-graded aggregate-asphalt hot-mix that maximizes the asphalt cement content and coarse aggregate fraction. This provides a stable stone-on-stone skeleton that is held together by a rich mixture of asphalt cement, filler, and stabilizing additive.

SMA was developed in Germany during the mid 1960's. The original purpose of SMA was to provide a mixture that offered maximum resistance to studded tire wear. SMA has also been shown to have an extremely high resistance to plastic deformation (rutting) created by heavy wheel loads at high temperatures. At the same time, SMA mixtures have exhibited good low temperature properties.[1] SMA is now in regular use for surface courses in much of Europe.

SMA is not like typical dense-graded mixtures used in Illinois. A typical dense-graded asphalt concrete mixture can have little to no stone-on-stone contact, depending on the gradation. Figure 1 illustrates the difference between the internal structure of these two mixtures. Figure 2 and Figure 3 illustrate the gradation differences between a traditional Illinois hot-mix asphalt (HMA) and the recommended FHWA SMA gradation (Table 1). SMA contains much less of the sand fraction, making the mixture gap-graded. Europe has had best performance when using hard igneous rocks.[2] Illinois utilizes mainly carbonate rocks. SMA also has a higher asphalt content (6 to 7 percent by weight of mixture). This higher asphalt content, when combined with the higher percentage of minus No. 200 sieve material (8 to 10 percent by weight of mixture), produces a mastic which increases the asphalt film thickness on the aggregate particles. This produces a mixture which is impermeable to water which makes SMA more durable.[3] Due to the higher asphalt content and the gap-graded gradation, a modifier must be added to prevent drain-down during mixing, hauling, and placement of the mixture. Types of modifiers normally used are cellulose fibers (0.3 to 0.5 percent by weight of asphalt), mineral fibers (0.4 to 0.5 percent by weight of asphalt), or a polymer-modified asphalt.

From European experiences, the advantages of SMA were found to be high resistance to rutting, improved low temperature performance, improved macro texture, increased service life, reduction of tire noise, and ease of compacting with heavy static rollers. Many experts believe SMA's to be a most promising mixture which can be adopted for use in the United States.

Based on the above information, IDOT decided to construct several experimental projects utilizing SMA.

## Experimental SMA

Illinois' first SMA project was an experimental project located on the south Schuyler/north Brown county line on Illinois Route 24 in District Six. The project, built in late 1992, consisted of cold-milling an existing asphalt concrete overlay to a 10-inch jointed portland cement concrete pavement and placing 1-3/4 inches of SMA. The project consisted of 10 lane miles. Only 7.5 miles were constructed with SMA, totaling 4,050 tons of SMA mix. The remaining 2.5 miles consisted of a Class I Type 2 surface mixture D.

The contractor was Diamond Construction. The plant was an Aztec, Model 6-Pack drier-drum hot-mix plant rated at 252 tons per hour.

Since the project was experimental and methodology of SMA was so new, consultants were hired by the contractor to design and proportion the mixture, supervise laydown, and summarize the project in a final construction report. Since this project impacted an existing contract already awarded, there was no special provision. The project was controlled under the guidance of the consultants who were considered experts on SMA mixtures.

The following ingredient materials were obtained by IDOT and sent to both Elf Asphalt (presently known as Koch Materials) and the National Center of Asphalt Technology (NCAT) to perform mix designs: 1/2-inch to 3/8-inch aggregate, 3/8-inch to No. 16 aggregate, minus No. 4 aggregate, mineral filler, and polymer-modified asphalt (referred to as a MAC20HD). The 1/2-inch to 3/8-inch aggregate was a specially sized material produced by Material Service's Romeoville Quarry and referred to as CM00 (Table 2). Through the utilization of CM00, the mixture gradation was of the "large SMA" gradation type and would meet the FHWA recommended gradation ranges. The 3/8-inch to No. 16 sized material, produced by Material Service, was a common CA16 gradation. The minus No. 4 material was an FA20 gradation (manufactured sand) produced by Central Stone's Barry Quarry, and the mineral filler was produced by J. M. Huber Company of Quincy, Illinois. The polymer-modified asphalt (MAC20HD) was produced by Elf Asphalt.

Upon reviewing the completed mix designs, IDOT decided to use NCAT's design (Appendix A). However, due to the difference in asphalt contents of the two designs, a test strip for each design was constructed off site. On August 31, 1992, two separate 100-ton test strips were constructed using both Mix 1 and Mix 2 (Table 3). The reflux extraction test results are listed in Table 4. Final acceptance of densities were determined by cores. However, nuclear gauges were used to spot-check. The nuclear density gauges closely represented the core densities. From the core densities it was determined to utilize the vibratory roller in vibratory mode for two passes, followed by four static passes, and then followed by a finish roller. As an experiment, a rubber-tired roller in the breakdown position was used on the preliminary test strips. However, no significant increase in densities was found.

Six different job mix formulas were used throughout the project as listed in Table 3.

After the data from the test strips were analyzed, it was determined to average the asphalt content from the two designs and run the mix at 6.0 percent asphalt due to both the air voids and core test results.

The project was started on September 10, 1992, and Mix 3 was initiated. However, due to excessive flushing with Mix 3, Mix 1 was again used. The test results are listed in Table 4.

The next day was started with Mix 1, followed by Mix 4, Mix 5, and Mix 6. Test results are listed in Table 4. Again, there was a constant problem with flushing. All the areas that flushed were no larger than 10 square feet. These areas were very predictable; they would occur when the paver was waiting for the next truck. It would physically occur at the slats on the paver conveyor, starting between the augers and screed.

The last day of SMA production consisted of Mix 6. Test results are listed in Table 4.

Summarized below are problems that were encountered on the first SMA experimental project.

- Mixture temperatures fluctuated from 300° F to 350° F. This is believed to be caused by the coarse nature of the mixture gradation. It was difficult to obtain a proper veil of aggregate in the drier-drum which caused poor heat dispersion between aggregate particles. These fluctuations in temperatures made the mixture even more sensitive to drain-down (flushing).

- Flushing was a frequent occurrence. As stated earlier, a MAC20HD was utilized as the modified asphalt. All of the flushing areas were less than 10 square feet in size, and all the areas were predictable. Flushing would physically occur at the slats on the paver conveyor and would start between the augers and screed while waiting for the next truck. Flushing may also have been caused by the screed physically collecting the mastic portion of the mix while paving; when the paver stopped, this material dropped onto the mat. Another possibility was the varying temperatures at the plant. When the temperature spikes exceeded 330° F, it could have caused the polymer-modified asphalt to become less viscous which produced drain-down during transit. This would then look like the beginning of the load flushing at the slat conveyor. The average haul distance was 15 miles one way.

- Due to the viscous nature of the MAC20HD, it was difficult for the asphalt pump to pump the required amount of asphalt at the higher production rates. Therefore, the plant produced mix at the rate of 175 to 190 tons per hour. This decrease in tonnage also made controlling the mixture temperature more difficult by reducing the aggregate veil in the drier-drum.

- The mixture was extremely sticky. It was very difficult to keep the truck beds clean from load to load. In fact, early in the project, the gob hopper itself would not open due to the sticky nature of the mixture; the plant operator had to make an emergency stop of the plant. This type of shutdown caused a problem with the slat conveyor; SMA material was still in the slat and had to be manually removed.

- There were stockpile gradation control problems. It became apparent that aggregate gradation is a critical factor in producing SMA, as it is with any gap-graded mixture.

Overall the project was a good learning experience. Today, the project looks good structurally. However, it is not pleasing aesthetically. There are numerous "fat spots". Snow plows have also chattered the surface, leaving alternating dark and light areas throughout the project. There is some reflective cracking. However, the pavement edges look great, unlike the crumbling edges of the dense-graded control section.

## Selection Criteria - Additional SMA Projects

After the experience with the experimental SMA project in the summer of 1992, each Illinois highway district was asked to submit possible candidate projects to be constructed in 1993. The projects were required to meet the following criteria:

- minimum handwork
- minimum average daily traffic (ADT) of 6,000 with large truck volume
- minimum of 3,000 tons

Five projects meeting the criteria were submitted to be constructed during the summer of 1993. Only two were actually constructed. The other three projects were not constructed in 1993 for one or more of the following reasons:

- The aggregate (except natural sand) was required to be produced by a source under the Aggregate Source Certification Program (currently referred to as Aggregate Gradation Control System).
- There were problems in producing the specially sized CM00 aggregate (100 percent passing the 3/4-inch sieve, 65 ± 10 percent passing the 1/2-inch sieve, and 3 ± 3 percent passing the No. 8 sieve).
- Bid prices received were continually over the Engineer's cost estimate.

The three contracts remaining, all the "large SMA" gradation type, were constructed in the 1994 construction season.

Each SMA project had a special provision written solely for that project. All the special provisions were essentially the same with the following differences: mixture gradation ranges (small or large) and type of modifier used (cellulose fibers, mineral fiber, or polymer asphalts). Therefore, each special provision was tailored to address what IDOT wanted to evaluate on a project-by-project basis.

Table 5 lists each of the seven SMA projects, the year each project was constructed, the district in which the project was constructed, the type of gradation (small or large), and the type of modifier used.

## District Six Project

The District Six SMA project consisted of 2.16 miles of two lanes at 24-foot and variable width resurfacing with bituminous Stone Matrix Asphalt on FAI 72 (U.S. Route 36) from Old Chatham Road to Sixth Street and 48-foot and variable width resurfacing with bituminous Stone Matrix Asphalt on Business (FAI) Route 55 from Hazel Dell Road to 0.3 mile south of Interstate Route 55 in Springfield, Illinois. The project, built in 1993, consisted of overlaying a 10-inch jointed portland cement concrete pavement. The average daily traffic (ADT) on U.S. 36 and I-55 was 22,600 and 22,700, respectively. The multiple units (MU's) on U.S. 36 and I-55 were 1,550 and 5,000, respectively. The total SMA tonnage was placed in two lifts and was 18,420 tons. The nominal thickness of the first lift was 1-3/4 inches, and the second lift was 1-1/2 inches.

Construction began on the District Six cellulose-modified SMA job on August 27, 1993. The SMA mixture was comprised of CA16 (3/8-inch chip), FA21 (unwashed manufactured sand), mineral fibers, and cellulose fibers. This was IDOT's first attempt in constructing a "small SMA" gradation. IDOT was interested in the feasibility of constructing an SMA mixture with native aggregates which were currently being produced in an attempt to keep the cost down. Therefore, IDOT designed the mixture to meet a German 3/8-inch SMA gradation (Figure 4). The design data is shown in Appendix B. The mix gradation ranges allowed for a high percent passing the No. 4 sieve. The percent passing the No. 4 in the mix design was 48 percent. This is 20 percent finer than the SMA mix gradation recommended by FHWA.

The SMA was produced by Sankey Construction using a Cedarapids, Model BM-570 hot-mix bituminous batch plant located in Springfield, Illinois. The mix was produced using both 5,000-pound and 6,000-pound batch weights which required a minimum of 15 pounds and 18 pounds of cellulose fiber per batch, respectively. The cellulose fibers were supplied by Central Fiber Corporation, Wellsville, Kansas. The cellulose fibers were added manually into a calibrated pneumatic blower which blew the fibers into the weigh hopper. The fibers were introduced over a prescribed period of time while the weigh hopper was being charged with aggregate. This allowed for adequate dispersion of the fiber. Both the dry and wet mixing times were increased 5 seconds for a total mixing time of 55 seconds per batch.

A 300-ton preliminary test strip was constructed off site on August 24, 1993, to verify the mix design and to familiarize both the contractor and IDOT personnel with the cellulose-modified SMA mixture. The preliminary test strip was constructed in accordance with IDOT's procedure for "Preliminary Test Strip and Modified Start-Up for Stone Matrix Asphalt (SMA) and Crumb Rubber Asphalt (RUMAC) Mixtures" (Appendix C). From the production test data collected from the preliminary test strip, it was decided to take out one percent mineral filler in an attempt to increase air voids.

Construction began on the District Six cellulose-modified SMA job, on August 27, 1993. Test results are listed in Table 6.

The SMA was placed utilizing conventional methods and equipment. The rollers and rolling patterns were changed periodically to investigate which would achieve the best density.

Several problems occurred on this project. There was difficulty in getting a good nuclear/core correlation. Therefore, the District used cores for final acceptance and spot-checked densities with a correlated nuclear density gauge, as outlined in the SMA Special Provision.

A problem which appeared during the construction of the first lift was excessive humping or rollover. It was deemed to be caused by one or more of the following:

- Untreated transverse cracks in the concrete which was being overlaid.
- Sensitivity of the mixture temperature.
- Tenderness of the mixture.

Humps exceeding 1/2 inch were milled prior to the surface course to ensure a smooth overlay.

There was also a problem with random areas of "fat spots" on the second lift. These fat spots were no bigger than 2 inches in diameter. The fat spots were determined to be clumps of cellulose fibers that were not properly mixed. Therefore, it was determined a homogenous dispersion of the cellulose fibers is essential in preventing drain-down in the SMA mixture.

In conclusion, this project was the first of two projects which used the "small SMA" gradation type (1/2-inch top size). The mix did not meet the recommended FHWA gradation, which requires 3/4-inch top size. It should be noted that the percent passing the No. 50 sieve and the voids in the mineral aggregate (VMA) in the mix design did not meet specifications. Due to the fineness of the mixture (specifically, the percent passing the No. 4), the gradation moved away from being gap-graded and produced a tender mixture.

## District Two Project

The District Two SMA project was located on Interstate Route 80 between Colona and Geneseo (east of the Interstate Route 74 interchange). The project, built in 1993, consisted of cold-milling 3-1/4 inches of an existing asphalt concrete overlay on a 10-inch jointed portland cement concrete pavement. The ADT on I-80 was 15,800 with 4,100 MU's. The total SMA tonnage was 15,200 tons which was inlayed in two lifts. The nominal thickness of the first lift was 1-3/4 inches, and the second lift was 1-1/2 inches.

The SMA mixture was comprised of CA13 (1/2-inch chip), FA20 (manufactured sand), mineral filler, and cellulose fibers. This was IDOT's second attempt at constructing a "small SMA" gradation. The design data is shown in Appendix D.

The SMA was produced by McCarthy Improvement Company using a Cedarapids Model G650C hot-mix bituminous batch plant. The mix was produced using a 7,000-pound batch which required a minimum of 21 pounds of cellulose fiber per batch. The cellulose fiber was supplied by Central Fiber Corporation, Wellsville, Kansas. The fiber was bagged in melt-away plastic bags weighing 21 pounds per bag. The fibers were to be added manually into the pug mill. However, the chute where the fibers were to be added was too small for a bag which resulted in a lot of spillage. Therefore, a small hay mulcher was used to charge the pug mill with cellulose fibers. The dry and wet mixing times were 20 seconds and 50 seconds, respectively, for a total of 70 seconds per batch. The increased mixing times were needed to uniformly mix the fibers into the mixture.

A 300-ton preliminary test strip was constructed off site on September 8, 1993, to verify the mix design and familiarize both the contractor and IDOT personnel with the cellulose-modified SMA mixture as outlined in the Special Provision. The preliminary test strip was constructed in accordance with IDOT's procedure for "Preliminary Test Strip and Modified Start-Up for Stone Matrix Asphalt (SMA) and Crumb Rubber Asphalt (RUMAC) Mixtures" (Appendix C). During the preliminary test strip, a set of hot bins showed the No. 8 sieve to be 6 percent high, which corresponded with visual observations of the mixture being fine. Therefore, the mix was adjusted.

Construction began on the District Two cellulose-modified SMA job on September 15, 1993. Test results are listed in Table 7.

The SMA was placed utilizing conventional methods and equipment. Both lanes were milled prior to placement of the SMA, and the shoulders remained in place. Therefore, the SMA was pinched between the shoulders. The vibratory rollers were operated in the vibratory mode to achieve density.

No significant problems were encountered throughout the project.

In late 1994, a pavement inspection revealed rutting in the outside lane, predominantly on the inner wheel path. The rut depths were between 1/4 and 3/8 inch. As of August 1995, the rutting did not appear to be any worse. This is very encouraging since the temperatures for the 30 days prior to the August 1995 inspection had been approximately 90° F with pavement temperatures probably in excess of 140° F. The surface color and texture of the SMA on the road is still darker gray with respect to the adjoining sections that are not SMA. No flushing is evident. There is some reflective cracking in the pavement from the working joints of the underlying pavement. The overall condition of the surface is good to excellent.

## District One Project

The District One SMA project was located on Illinois Route 394 (Calumet Expressway) for 2.4 miles east of Crete township. The project, built in 1994, consisted of overlaying a 10-inch jointed portland cement concrete pavement. The ADT of Illinois Route 394 was 25,100 with 3,500 MU's. The total SMA tonnage was 7,650 tons and was placed in a 1-3/4-inch overlay.

The SMA mixture was comprised of CM00 (minus 3/4 inch and plus 3/8 inch), CM16 (3/8-inch chip), FM20 (manufactured sand), mineral filler, and cellulose fibers. The design data is shown in Appendix E. The SMA gradation was of the "large SMA" gradation.

The SMA was produced by Gallagher Asphalt using a Barber Greene Model BH-200 hot-mix bituminous batch plant. The mix was produced using a 10,000-pound batch which required a minimum of 30 pounds of cellulose fiber per batch. The cellulose fiber was supplied by Central Fiber Corporation, Wellsville, Kansas. The fiber was bagged in melt-away plastic bags weighing 30 pounds per bag. The cellulose fibers were introduced into the plant via the RAP belt (into the pug mill). No anti-strip was added.

On May 31, 1994, a 300-ton preliminary test strip was constructed off site as outlined in the Special Provision (Appendix F). The preliminary test strip was constructed in accordance with IDOT's procedure for "Preliminary Test Strip and Modified Start-Up for Stone Matrix Asphalt (SMA) and Crumb Rubber Asphalt (RUMAC) Mixtures (Appendix C). The test strip was located on a major haul road that serviced Material Service's Thornton Quarry. In order to properly produce the SMA mixture from the five-bin batch plant, two of the screen decks had to be pulled. However, from the gradation analysis it was discovered that the wrong screen decks were pulled. In addition, the wrong CA16 stockpile was being hauled from the quarry and dumped into the bunker which was charging the asphalt plant. In spite of these oversights, the test strip was constructed with few difficulties, and the section is performing adequately with no apparent distresses.

All the problems were corrected prior to SMA start-up. Construction began on the District One cellulose-modified SMA job on June 15, 1994. The test results are listed in Table 8.

The contractor utilized two heavy steel-wheeled rollers instead of the required vibratory rollers outlined in the Special Provision. Both rollers were weighted down with steel plates to reach a minimum of 325 pounds per lineal inch. This worked well for obtaining density. The only problem encountered throughout the project was the breakdown of plus No. 4 material. This was believed to be caused by either the elongated dolomite aggregate particles or the steel-wheeled rollers.

No significant problems were encountered throughout the project. The SMA is in good to excellent condition.

## District Eight Project

The District Eight SMA project was located on Interstate Route 55, north of the Interstate Route 55, Interstate Route 70, and Interstate Route 270 interchange. The project, built in 1994, consisted of cold-milling 3-1/4 inches of an existing 16-inch composite pavement. The ADT on I-55 was 21,500 with 4,000 MU's. The total SMA tonnage was 2,000 which was placed on two lifts. The nominal thickness of the first lift was 1-3/4 inches, and the second lift was 1-1/2 inches.

The SMA mixture was comprised of CM00 (minus 3/4-inch and plus 3/8-inch), CM13 (3/8-inch chip), FA20 (manufactured sand), mineral filler, and mineral fibers. The design data is shown in Appendix G. The SMA gradation was of the "large SMA" gradation type.

The SMA was produced by Maclair Asphalt using a Barber Greene Model BE 150 hot-mix bituminous batch plant rated for 10,000-pound batches. The mix was produced using a 8,400-pound batch which required 60 pounds of mineral fiber per batch. The mineral fiber was supplied by Fiberand Corporation of South Miami, Florida. The fiber was bagged in melt-away bags weighing 40 pounds per bag. The mineral fibers were introduced into the weigh hopper utilizing two insulation blowers.

On July 5, 1994, a 300-ton preliminary test strip was constructed on I-55, 2 miles north of the I-70/270 interchange. The preliminary test strip was constructed in accordance with IDOT's procedure for "Preliminary Test Strip and Modified Start-Up for Stone Matrix Asphalt (SMA) and Crumb Rubber Asphalt (RUMAC) Mixtures (Appendix C).

Construction began on the District Eight mineral fiber-modified SMA job on July 7, 1994. Test results are listed in Table 9. Due to the amount of fibers needed per batch, mixing times were increased to 80 seconds (not including the 45 to 50 seconds it took to put the mineral fibers up into the pug mill). Since the overall time to produce a single batch was increased significantly, the plant needed to be shut down intermittently due to the hot bins filling up. These intermittent shutdowns produced temperature spikes in the mixture.

There was excessive flushing which occurred throughout the job. It was believed to be caused by one or more of the following:

- Asphalt content was too high.
- Dosage rate of mineral fibers was too high.
- Temperature spikes at the plant made it impossible to control mix temperature.
- Difficulty in mixing the SMA and mineral fibers to a homogenous state.
- The mineral fibers themselves breaking down due to the long mixing times per batch.

In August 1995, a pavement inspection revealed that there was rutting in some areas. During the whole month of July, Illinois experienced temperatures in excess of 90° F. The northbound driving lane shows rutting ranging from 1/4 inch to 1/2 inch, particularly the last 600 feet which has 3/8-inch to 1/2-inch ruts. The southbound driving lanes are also exhibiting rutting with a 40- to 50-foot section having 1-1/2-inch ruts.

In October 1995, full-depth 10-inch cores and slabs were cut to determine the probable cause of the distress. Visually, the older binder course, which was not completely milled off prior to overlaying (approximately 2 inches in depth on top of the 10-inch jointed portland cement concrete pavement), was stripping. Results from six gyratory stability specimens showed an average gyratory stability index (GSI) value of 1.378 which suggests this layer to be unstable. It is believed this is what is causing the rutting.

## District Three Project

The District Three SMA project was located on Interstate Route 57 from Kankakee to 2 miles south of Manteno, Illinois. The project, built in 1994, consisted of a 3-1/4-inch overlay on an existing 13-inch composite pavement. The ADT on I-57 was 19,500 with 3,374 MU's. The total SMA tonnage was 2,850 which was placed in two lifts. The lifts had a nominal thickness of 1-3/4 inches and 1-1/2 inches, respectively.

The SMA mixture was comprised of CM00 (minus 3/4-inch and plus 3/8-inch), CM13 (1/2-inch chip), FA20 (manufactured sand), mineral filler, and polymerized asphalt (MAC20). The design data is shown in Appendix F. The SMA gradation was of the "large SMA" gradation type.

The SMA was produced by Azzarelli Construction using a Gencor/Bituma Model UD-400 drier-drum rated at 415 tons per hour. The auger in the mineral filler system had to be altered to introduce the required 8.5 percent mineral filler.

On July 26, 1994, a 300-ton preliminary test strip was constructed off site as outlined in the Special Provision. The preliminary test strip was constructed in accordance with IDOT's procedure for "Preliminary Test Strip and Modified Start-Up for Stone Matrix Asphalt (SMA) and Crumb Rubber Asphalt (RUMAC) Mixtures (Appendix C). The test strip was located off of Illinois Route 50 on a low-volume road in front of the Azzarelli asphalt plant.

Construction began on the District Three polymer-modified asphalt job on July 26, 1994. It was determined that air temperature and wind play an important role during laydown operations, particularly in obtaining densities.

Test results are listed in Table 10.

There was some random flushing in the wheel lanes. It was deemed to be caused by one or more of the following:

- Low voids in the mineral aggregate.
- At times a higher concentration of release agent was used which could have stripped the asphalt from the aggregate particles.
- The mastic portion of the mix (minus No. 8 material and asphalt) would clump to the bottom of the paving screed and periodically fall onto the freshly place mat.

There were excessive amounts of SMA sticking in the truck beds after each load. The following methods were attempted to alleviate this sticking problem:

- Increasing release agent concentration.
- Using new release agent supplied by Koch.

Once the truck beds got warm, the amount of SMA sticking was reduced significantly.

## District One Steel Slag Project

A steel slag SMA test section was constructed by The Levy Company at their Gary, Indiana steel plant. The purpose of the test section was to give IDOT, the Indiana Department of Transportation, and The Levy Company experience with a steel slag SMA and to determine if steel slag can be used as an alternative aggregate in SMA. This particular test section was not a full-blown investigation project.

The steel slag SMA was comprised of CM00 (minus 3/4-inch and plus 3/8-inch), FA20 (manufactured sand), mineral filler, and polymerized asphalt. The steel slag CM00 gradation was a coarse Indiana Grade 9 and is listed in Table 11. Seneca Petroleum supplied a modified asphalt, MAC20HD. The design data is shown in Appendix H. The SMA gradation was of the "large SMA" gradation type. The design was done by IDOT District One Materials. The test section (500 tons) was paid in full by The Levy Company. The mix was produced in Indiana by a plant which is not Illinois-approved.

Construction began on the steel slag polymer-modified SMA job on November 8, 1994. The experimental section went well. One problem that was identified was the mix sticking to the truck beds.

To this date the section is holding up very well. This is very encouraging because the test section was placed on an approach to a scale house. The trucks which use this scale house weigh in excess of 150 tons when loaded. Also, large loaders with steel tracks utilize the paved section. These loaders and trucks have tight turning radii. The pavement has exhibited no distresses to date. All the Indiana Class I mixtures used in the past at this location have failed prematurely.

From the pavement's performance, using steel slag in SMA mixtures may be extremely beneficial to IDOT. The steel slag SMA may be used to provide the necessary pavement friction and replace conventional mixes that have always rutted in the past due to loading.

## Mix Design

The first two SMA projects (in District Six and District Two) were designed following the Marshall method of design due to the lack of literature on how to design SMA's. The District One SMA project was designed attempting a procedure outlined in the proceedings of the Thirty-Eighth Annual Conference of Canadian Technical Asphalt Association. This procedure showed that SMA is a hot-mix asphalt consisting of two components: a coarse aggregate skeleton and a binder-rich mortar consisting of asphalt cement, fine aggregate, mineral filler, and stabilizing additive. The coarse aggregate skeleton is nearly filled with, and held together by, the mortar. Because SMA is quite different from conventional mixtures, it is necessary to divide the design stage into three parts:

- Coarse aggregate skeleton design
- Binder-rich mortar design
- Coarse aggregate skeleton/mortar proportioning

IDOT attempted this design concept with the District One SMA design. However, the procedure did not work for Illinois for the following reasons:

- The blend that was created was nonreproducible in the field.
- The primary aggregate skeleton could not be properly determined due to Illinois carbonate aggregates. The procedure required the plus 3/8-inch sized aggregate in the CM00 and the minus 3/8-inch in the chip to be combined with 5 percent mineral filler and 3 percent asphalt, and compacted in the Marshall hammer at a predetermined number of blows. This procedure was found to produce 16 to 28 percent degradation on the plus 3/8-inch material, depending on the coarse aggregate blend. The voids in the primary aggregate skeleton could not be accurately computed.

The remaining designs were done using the current Illinois standard, the Marshall Method of design (very similar to NCAT's Interim Report, "Designing Stone Matrix Asphalt Mixtures Volume III - Tentative Mixture Design Method").

## Performance

Although the intent of this study was to gain knowledge and experience in the design, production, laydown, type of modifier, and type of gradation of SMA's, early pavement performance was also monitored.

Pavement friction properties were measured. Six (6) to 9 months after placement, the SMA's friction properties are very comparable to conventional mixtures utilizing similar aggregate types.

In addition, four of the seven SMA projects were tested in the Hamburg Wheel Tracking Device (HWTD). The HWTD is considered a torture test. The test is performed using a steel wheel loaded at 215 psi. The wheel reciprocates over a 9-inch long track, taking about one second for each pass. The specimen is completely submerged in a 50° C (122° F) water bath, making the HWTD a valuable tool for evaluating both the rutting and stripping potential of asphalt mixtures. After each pass of the wheel, vertical deformation is measured automatically at the center of the specimen to the nearest 0.01 mm. Tests are run for 20,000 cycles (passes), or until the rut depth reaches 20 mm, at which time the test is halted. Currently there is no correlation between a minimum number of passes and traffic levels.

Germany, the forefather of the HWTD, currently requires their higher type mixtures to have no more than 4-mm deformation after 20,000 cycles. Colorado's Eurolab is presently recommending mixtures up to 10-mm deformation after 20,000 cycles for their higher type mixtures. Therefore, as shown in Table 12, five out of the fourteen SMA cores would meet Colorado's criteria, but only one would meet Germany's harsh requirements. It is interesting to note that all the cores representing flushed areas failed.

Koch Materials in Terre Haute, Indiana, tested Illinois dense-graded Class I Type 1 and Type 2 mixtures composed of crushed gravel in the HWTD. The Type 1 had 20-mm deformation at 16,000 passes while the Type 2 had 11.5-mm deformation at 20,000 passes. No conclusions were developed from the test results since only one test specimen from each mix type was tested.

IDOT was interested in comparing SMA's with typical dense-graded mixtures. As shown in Table 12, Cores 5, 7, 13, and 14 had deformations lower than both IDOT's Type 1 and Type 2 mixtures above when the samples were taken in a non-flushed area.

The HWTD results show that SMA's may have a tendency to strip. With this concern in mind, future SMA projects will require the use of anti-strip additives.

In conclusion, the HWTD results show that SMA's when properly designed and constructed in the field do provide a good stable mixture.

## Cost

The cost per ton of SMA, as listed below, includes asphalt, placement, and compaction. Listed below is the cost information for each SMA project:

| Year Constructed | District | Type SMA | Modifier | Conventional HMA (average cost/ton/district) | SMA (cost/ton) | Percent Increase |
|---|---|---|---|---|---|---|
| 1992 | 6 | Large | Polymerized Asphalt | $32.00 | $44.55 | 39 |
| 1993 | 6 | Small | Cellulose Fiber | $34.00 | $41.55 | 22 |
| 1993 | 2 | Small | Cellulose Fiber | $28.00 | $39.60 | 41 |
| 1994 | 1 | Large | Cellulose Fiber | $29.00 | $42.00 | 45 |
| 1994 | 8 | Large | Mineral Fiber | $37.00 | $44.25 | 20 |
| 1994 | 3 | Large | Polymerized Asphalt | $34.00 | $60.00 | 76 |
| 1994 | 1 | Large | Polymerized Asphalt | $29.00 | $41.30 | 42 |

The average cost of all projects is $44.71 or an average percent increase of 41 percent. The District Three project's cost of $60 per ton is largely influenced by the cost of producing the specially sized CM00 aggregate ($80 per ton).

## Future

It is the goal of IDOT to continue to expand the technology of SMA in Illinois. Each district was again solicited to submit candidate project(s). The selection criteria for the candidate project(s) were recommended to meet the same requirements as listed on page 8 herein. As of the date of this report, two candidate projects have been received.

- The first project will be a steel slag SMA utilizing a polymerized asphalt as its modifier in District One. This shall be constructed in the 1996 construction season.

- The second project will be a dolomite SMA constructed in 1996 in District Nine. The modifier has not yet been selected.

## Specification Changes

The following specification changes will be made on future SMA projects:

1. Elimination of the "small SMA" gradation. IDOT will produce SMA mixtures which will meet the gradation ranges recommended by FHWA.

2. The individual aggregate gradations will no longer be specified as ingredients. The contractor may submit any type of aggregates for design provided the aggregates meet the quality requirements and the final aggregate blend meets the gradation ranges recommended by FHWA.

3. Breakdown rollers will be of the static type meeting a required minimum of 325 pounds per lineal inch (PLI). Vibratory rollers may be added per the Engineer's judgment to obtain proper density requirements.

4. Anti-strip additives will be required to reduce stripping potential.

5. Final density acceptance will continue to be based on cores instead of nuclear density gauges.

## Conclusions/Recommendations

Though the success of SMA in Illinois has been limited to only a few projects, it is believed that SMA may replace IDOT's higher type mixtures in certain applications. However, SMA will not replace dense-graded Class I mixtures across the board. It should not be considered a "mixture to end all mixtures". SMA may be used in areas of heavy truck traffic, areas of heavy and congested traffic, and areas where rutting has been a continual problem.

Through the utilization of the new SMA mix design procedures and further evaluation of existing projects, SMA can be a cost effective alternative mixture in these application areas.

Based on the work done in this study, the following conclusions are made:

1. Future SMA projects will consist of the "large SMA" mix gradation which meets the recommended FHWA gradation. The "small SMA" mix gradation investigated did not perform or look like an SMA mixture. The "small SMA" mixtures were predominantly tender and looked like conventional surface mixtures.

2. Cost, as always, is a concern. The average cost of the seven SMA projects was $44.71 per ton, an average increase of 41 percent to that of dense-graded Class I mixtures. With the increase in experience with SMA and through competitive bidding, it is believed this cost will be reduced.

3. All modifiers - cellulose fibers, mineral fibers, and polymerized asphalts - will continue to be evaluated on future projects. There was no significant increase in cost related to type of modifier used.

4. SMA mixtures are very sticky, especially the polymer-modified SMA. Nothing seemed to reduce this phenomena.

5. The plant type did not affect the constructability of the mixture. Both batch and drier-drum plants produced a homogenous mixture. Some plant modifications were required to introduce the modifier.

6. Both mixing and laydown temperatures are critical, more so than with typical dense-graded mixtures. This is due to the gap-graded nature of the mixture and type of modifier. If the mixture was produced too hot, drain-down would occur; if the laydown temperature was too low, obtaining densities was very difficult.

7. Future SMA projects will use heavy static rollers (minimum 10 tons) in the breakdown position. It is believed the lighter vibratory rollers may have degraded Illinois' carbonate aggregates instead of seating the mixture.

8. Frictional properties tend to be slightly lower early in the pavement's life due to the increased asphalt film thickness. Therefore, future SMA's may require blotting the pavement surface with a manufactured sand.

9. In 1996, Illinois is intending to construct an SMA project consisting of steel slag SMA in the Chicago area. This is due to the experience with Levy's experimental section in Indiana.

10. Future SMA projects will be designed following NCAT's interim report.

## References

1 "Stone Mastic Asphalt (SMA) Technical Information", Michigan Department of Transportation, Lansing, Michigan, 1991.

2 "Report on the 1990 European Asphalt Study Tour", American Association of State Highway and Transportation Officials, Washington, D.C., 1991.

3 Carpenter, S., "Stone Matrix Asphalt (SMA) Mixtures Final Report", University of Illinois, 1994.

## FHWA SMA Mix Gradation Requirements

| Sieve | Percent Passing |
|---|---|
| 3/4 inch | 100 |
| 1/2 inch | 85 - 95 |
| 3/8 inch | 75 (max) |
| No. 4 | 20 - 28 |
| No. 8 | 16 - 24 |
| No. 30 | 12 - 16 |
| No. 50 | 12 - 15 |
| No. 200 | 8 - 10 |

Table 1

## CM00 Gradation Requirements

| Sieve | Percent Passing |
|---|---|
| 3/4 inch | 100 |
| 1/2 inch | $65 \pm 10$ |
| 3/8 inch | $3 \pm 3$ |

Table 2

## Experimental SMA Mix Blends

| Aggregate Sizes | Mix 1 (%) | Mix 2 (%) | Mix 3 (%) | Mix 4 (%) | Mix 5 (%) | Mix 6 (%) |
|---|---|---|---|---|---|---|
| 1/2 inch to 3/8 inch | 60 | 60 | 60 | 65 | 65 | 60 |
| 3/8 inch to No. 16 | 25 | 25 | 25 | 15 | 15 | 25 |
| Minus No. 4 | 7 | 7 | 7 | 12 | 12 | 7 |
| Filler | 8 | 8 | 8 | 8 | 8 | 8 |
| AC | 5.8 | 6.2 | 6.0 | 5.8 | 5.6 | 5.7 |

Table 3

Test Results
Mixture Properties
District 6-Diamond Construction

| Sieve Size | Design | 08/31/92 Mix 1 Sample 1 | 08/31/92 Mix 1 Sample 2 | 08/31/92 Mix 2 Sample 1 | 08/31/92 Mix 2 Sample 2 | 09/10/92 Mix 3 Sample 1 | 09/10/92 Mix 3 Sample 2 | 09/10/92 Mix 1 Sample 1 |
|---|---|---|---|---|---|---|---|---|
| 3/4 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1/2 | 97 | 97 | 96 | 97 | 96 | 97 | 97 | 97 |
| 3/8 | 59 | 56 | 57 | 55 | 58 | 67 | 67 | 69 |
| #4 | 25 | 26 | 25 | 24 | 24 | 25 | 26 | 27 |
| #8 | 17 | 21 | 21 | 20 | 20 | 17 | 18 | 19 |
| #16 | 14 | 18 | 18 | 18 | 17 | 15 | 15 | 16 |
| #30 | 12 | 16 | 16 | 16 | 15 | 14 | 14 | 15 |
| #50 | 11 | 15 | 14 | 14 | 14 | 13 | 13 | 14 |
| #100 | 10 | 14 | 13 | 13 | 13 | 12 | 12 | 13 |
| #200 | 8.6 | 11.5 | 11.4 | 11.3 | 10.9 | 10.6 | 10.6 | 11.2 |
| Design AC | 5.8/6.2 | 5.8 | 5.8 | 6.2 | 6.2 | 6.0 | 6.0 | 5.8 |
| Extracted AC | | 5.6 | 5.4 | 5.8 | 5.7 | 5.6 | 6.2 | 5.5 |
| Gmm ("D") | 2.480/2.460 | 2.48 | 2.483 | 2.458 | 2.461 | 2.474 | NA | 2.463 |
| Gmb ("d") | 2.384/2.376 | 2.382 | 2.364 | 2.348 | 2.344 | 2.333 | NA | 2.344 |
| Stability | 1400 | 1800 | 1525 | 1600 | 1535 | 1793 | NA | 1814 |
| Flow | 16 | 11 | 13 | 13 | 13 | 9.8 | NA | 9.8 |
| Voids | 3.2 | 4 | 4.8 | 4.5 | 4.5 | 5.7 | NA | 4.8 |

Table 4

All marshall data were 50 blow specimens compacted at 325F
NA= Extraction only, no marshall tests

| Sieve Size | Mix Design | 09/11/92 Mix 4 Sample 1 | 09/11/92 Mix 5 Sample 1 | 09/11/92 Mix 6 Sample 1 | 09/14/95 Mix 6 Sample 1 | 09/14/95 Mix 6 Sample 2 | 09/14/95 Mix 6 Sample 3 | 09/14/95 Mix 6 Sample 4 |
|---|---|---|---|---|---|---|---|---|
| 3/4 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1/2 | 97 | 96 | 97 | 97 | 96 | 95 | 97 | 97 |
| 3/8 | 59 | 63 | 67 | 69 | 68 | 66 | 67 | 66 |
| #4 | 25 | 30 | 26 | 27 | 29 | 29 | 29 | 30 |
| #8 | 17 | 23 | 18 | 19 | 19 | 20 | 19 | 20 |
| #16 | 14 | 19 | 15 | 16 | 16 | 17 | 16 | 16 |
| #30 | 12 | 17 | 14 | 15 | 14 | 16 | 14 | 15 |
| #50 | 11 | 15 | 13 | 14 | 13 | 15 | 13 | 14 |
| #100 | 10 | 14 | 12 | 13 | 12 | 13 | 12 | 12 |
| #200 | 8.6 | 11.5 | 10.6 | 11.2 | 10.2 | 11.7 | 10.3 | 10.5 |
| Design AC | 5.8/6.2 | 5.8 | 5.6 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 |
| Extracted AC | | 5.6 | 5.3 | 5.9 | 5.4 | 5.1 | 5.4 | 5.5 |
| Gmm ("D") | 2.480/2.460 | 2.464 | NA | 2.468 | 2.484 | NA | 2.477 | NA |
| Gmb ("d") | 2.384/2.376 | 2.404 | NA | 2.315 | 2.349 | NA | 2.341 | NA |
| Stability | 1400 | 2261 | NA | 2012 | 1837 | NA | 1649 | NA |
| Flow | 16 | 11.4 | NA | 11.8 | 8.2 | NA | 10 | NA |
| Voids | 3.2 | 2.4 | NA | 6.2 | 5.4 | NA | 5.5 | NA |

Table 4 cont.

All marshall data were 50 blow specimens compacted at 325F
NA= Extraction only, no marshall tests

## SMA Projects

| Year Constructed | District | Gradation Type | Modifier |
|---|---|---|---|
| 1992 | 6 | Large | Polymerized Asphalt |
| 1993 | 6 | Small | Cellulose Fibers |
| 1993 | 2 | Small | Cellulose Fibers |
| 1994 | 1 | Large | Cellulose Fibers |
| 1994 | 8 | Large | Mineral Fibers |
| 1994 | 1 | Large | Polymerized Asphalt |
| 1994 | 3 | Large | Polymerized Asphalt |

Table 5

Test Results
Mixture Properties
District 6-Sankey Construction

| Sieve Size | Mix Design | 08/27/93 Sample 1 | 08/27/93 Sample 2 | 08/27/93 Sample 3 | 08/27/93 Sample 4 | 08/28/93 Sample 1 | 08/28/93 Sample 2 |
|---|---|---|---|---|---|---|---|
| 3/4 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1/2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 3/8 | 96 | 98 | 97 | 97 | 97 | 98 | 96 |
| #4 | 47 | 51 | 49 | 51 | 51 | 51 | 51 |
| #8 | 25 | 28 | 28 | 30 | 30 | 26 | 29 |
| #16 | 18 | 18 | 19 | 20 | 20 | 16 | 19 |
| #30 | 14 | 13 | 13 | 15 | 15 | 11 | 14 |
| #50 | 11 | 10 | 10 | 13 | 13 | 9 | 12 |
| #100 | 10 | 9 | 9 | 11 | 11 | 8 | 10 |
| #200 | 9.4 | 7.1 | 7.4 | 9.2 | 9.2 | 6.3 | 8.3 |
| Design AC | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 |
| Extracted AC | | 6.2 | 6.1 | 6.3 | 6.3 | 6.2 | 6.3 |
| Gmm ("D") | 2.48 | 2.47 | 2.48 | 2.47 | 2.47 | 2.46 | 2.47 |
| Gmb ("d") | 2.38 | 2.39 | 2.38 | 2.41 | 2.42 | 2.34 | 2.42 |
| Voids | 3.3 | 2.9 | 3.8 | 2.1 | 2.2 | 4.9 | 2.3 |

Table 6

All marshall data were 50 blow specimens compacted at 325F
NA= Extraction only, no marshall tests

| Sieve Size | Mix Design | 08/30/93 Sample 1 | 08/30/93 Sample 2 | 08/31/93 Sample 1 | 08/31/93 Sample 2 | 09/01/93 Sample 1 | 09/01/93 Sample 2 |
|---|---|---|---|---|---|---|---|
| 3/4 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1/2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 3/8 | 96 | 97 | 97 | 94 | 94 | 97 | 96 |
| #4 | 47 | 51 | 51 | 42 | 46 | 50 | 52 |
| #8 | 25 | 30 | 29 | 25 | 29 | 26 | 30 |
| #16 | 18 | 19 | 19 | 17 | 20 | 17 | 21 |
| #30 | 14 | 12 | 14 | 12 | 15 | 12 | 17 |
| #50 | 11 | 9 | 11 | 9 | 12 | 10 | 14 |
| #100 | 10 | 8 | 9 | 8 | 10 | 8 | 13 |
| #200 | 9.4 | 6.1 | 7.5 | 6.1 | 7.8 | 6.9 | 10.8 |
| Design AC | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 |
| Extracted AC | | 6.6 | 6.1 | 6.3 | 6.4 | 6.2 | 6.6 |
| Gmm ("D") | 2.46 | 2.47 | 2.47 | 2.44 | 2.46 | 2.47 | 2.46 |
| Gmb ("d") | 2.38 | 2.4 | 2.41 | 2.41 | 2.37 | 2.43 | 2.37 |
| Voids | 3.3 | 2.7 | 2.6 | 1.3 | 3.7 | 1.8 | 3.9 |

Table 6 cont.

All marshall data were 50 blow specimens compacted at 325F
NA= Extraction only, no marshall tests

Test Results
Mixture Properties
District 6-Sankey Construction

| Sieve | Mix | 09/08/93 | 09/08/93 | 09/08/93 | 09/10/93 | 09/10/93 | 09/10/93 |
|---|---|---|---|---|---|---|---|
| Size | Design | | | | | | |
| | | Sample 1 | Sample 2 | Sample 3 | Sample 1 | Sample 2 | Sample 3 |
| | | | | | | | |
| 3/4 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1/2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 3/8 | 96 | 97 | 95 | 96 | 96 | 97 | 97 |
| #4 | 47 | 42 | 40 | 45 | 49 | 46 | 49 |
| #8 | 25 | 22 | 21 | 22 | 24 | 24 | 27 |
| #16 | 18 | 15 | 14 | 15 | 16 | 17 | 18 |
| #30 | 14 | 11 | 10 | 12 | 13 | 13 | 14 |
| #50 | 11 | 9 | 8 | 11 | 11 | 11 | 11 |
| #100 | 10 | 8 | 7 | 10 | 10 | 10 | 9 |
| #200 | 9.4 | 7 | 6.1 | 8.3 | 8.3 | 8.3 | 6.3 |
| Design AC | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 |
| Extracted AC | | 6.4 | 6.6 | 6.2 | 6.1 | 6.3 | 5.9 |
| Gmm ("D") | 2.46 | 2.47 | 2.46 | 2.46 | 2.47 | NA | 2.48 |
| Gmb ("d") | 2.38 | 2.35 | 2.35 | 2.35 | 2.36 | NA | 2.39 |
| Voids | 3.3 | 5 | 4.6 | 4.3 | 4.8 | NA | 3.6 |

Table 6 cont.

All marshall data were 50 blow specimens compacted at 325F
NA= Extraction only, no marshall tests

| Sieve | Mix | 09/10/93 | 09/13/93 | 09/13/93 | 09/13/93 | 09/15/93 | 09/15/93 |
|---|---|---|---|---|---|---|---|
| Size | Design | | | | | | |
| | | Sample 4 | Sample 1 | Sample 2 | Sample 3 | Sample 1 | Sample 2 |
| | | | | | | | |
| 3/4 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1/2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 3/8 | 96 | 96 | 99 | 96 | 97 | 97 | 97 |
| #4 | 47 | 52 | 47 | 45 | 45 | 46 | 44 |
| #8 | 25 | 27 | 23 | 23 | 21 | 24 | 23 |
| #16 | 18 | 18 | 16 | 16 | 14 | 16 | 15 |
| #30 | 14 | 13 | 13 | 13 | 11 | 13 | 12 |
| #50 | 11 | 11 | 11 | 11 | 9 | 11 | 10 |
| #100 | 10 | 9 | 10 | 10 | 9 | 10 | 9 |
| #200 | 9.4 | 7.3 | 8.7 | 8 | 7.3 | 8.8 | 7.8 |
| Design AC | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 |
| Extracted AC | | 6 | 6 | 6.2 | 6.1 | 6.4 | 6.1 |
| Gmm ("D") | 2.46 | NA | 2.48 | 2.47 | 2.48 | 2.47 | 2.47 |
| Gmb ("d") | 2.38 | NA | 2.34 | 2.32 | 2.35 | 2.36 | 2.34 |
| Voids | 3.3 | NA | 5.6 | 6.3 | 5.2 | 4.5 | 5.1 |

Table 6 cont.

All marshall data were 50 blow specimens compacted at 325F
NA= Extraction only, no marshall tests

Test Results
Mixture Properties
District 6-Sankey Construction

| Sieve Size | Mix Design | 09/15/93 Sample 3 | 09/16/93 Sample 1 | 09/16/93 Sample 2 | 09/16/93 Sample 3 | 09/17/93 Sample 1 | 09/17/93 Sample 2 |
|---|---|---|---|---|---|---|---|
| 3/4 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1/2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 3/8 | 96 | 97 | 96 | 96 | 97 | 97 | 97 |
| #4 | 47 | 46 | 46 | 44 | 50 | 48 | 48 |
| #8 | 25 | 24 | 24 | 24 | 25 | 26 | 24 |
| #16 | 18 | 17 | 17 | 16 | 17 | 16 | 16 |
| #30 | 14 | 13 | 13 | 13 | 13 | 12 | 12 |
| #50 | 11 | 11 | 11 | 11 | 11 | 9 | 10 |
| #100 | 10 | 10 | 10 | 10 | 10 | 8 | 9 |
| #200 | 9.4 | 8.4 | 8.8 | 7.9 | 4.2 | 6.6 | 7.8 |
| Design AC | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 |
| Extracted AC | | 6.3 | 6.3 | 6.5 | 6.1 | 6.1 | 6.2 |
| Gmm ("D") | 2.46 | 2.46 | 2.46 | 2.5 | 2.47 | 2.46 | 2.48 |
| Gmb ("d") | 2.38 | 2.37 | 2.38 | 2.38 | 2.38 | 2.38 | 2.34 |
| Voids | 3.3 | 3.5 | 3.3 | 4 | 3.5 | 3.6 | 5.8 |

Table 6 cont.

All marshall data were 50 blow specimens compacted at 325F
NA= Extraction only, no marshall tests

| Sieve Size | Mix Design | 09/17/93 Sample 3 | 09/18/93 Sample 1 | 09/18/93 Sample 2 | 09/20/93 Sample 1 | 09/20/93 Sample 2 | 09/21/93 Sample 1 |
|---|---|---|---|---|---|---|---|
| 3/4 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1/2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 3/8 | 96 | 97 | 96 | 93 | 94 | 97 | 97 |
| #4 | 47 | 50 | 39 | 38 | 41 | 46 | 44 |
| #8 | 25 | 25 | 21 | 22 | 23 | 21 | 23 |
| #16 | 18 | 17 | 14 | 15 | 16 | 14 | 15 |
| #30 | 14 | 13 | 10 | 11 | 12 | 11 | 12 |
| #50 | 11 | 11 | 9 | 9 | 11 | 9 | 10 |
| #100 | 10 | 10 | 8 | 8 | 9 | 9 | 9 |
| #200 | 9.4 | 8.2 | 6.3 | 6.9 | 7.7 | 7 | 7.8 |
| Design AC | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 |
| Extracted AC | | 6.5 | 5.9 | 6 | 6.1 | 6 | 6.1 |
| Gmm ("D") | 2.48 | 2.47 | 2.49 | 2.48 | 2.47 | 2.48 | 2.47 |
| Gmb ("d") | 2.38 | 2.37 | 2.31 | 2.36 | 2.34 | 2.33 | 2.34 |
| Voids | 3.3 | 4.2 | 7 | 4.9 | 3.8 | 6.1 | 5.1 |

Table 6 cont.

All marshall data were 50 blow specimens compacted at 325F
NA= Extraction only, no marshall tests

Test Results
Mixture Properties
District 6-Sankey Construction

| Sieve Size | Mix Design | 09/21/93 | 09/21/93 | 09/27/93 | 09/27/93 | 09/28/93 | 09/28/93 |
|---|---|---|---|---|---|---|---|
| | | Sample 2 | Sample 3 | Sample 1 | Sample 2 | Sample 1 | Sample 2 |
| | | | | | | | |
| 3/4 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1/2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 3/8 | 96 | 97 | 98 | 95 | 95 | 96 | 97 |
| #4 | 47 | 45 | 47 | 47 | 45 | 46 | 46 |
| #8 | 25 | 22 | 23 | 25 | 24 | 23 | 25 |
| #16 | 18 | 15 | 16 | 17 | 17 | 16 | 17 |
| #30 | 14 | 12 | 13 | 13 | 13 | 13 | 14 |
| #50 | 11 | 11 | 11 | 11 | 11 | 11 | 12 |
| #100 | 10 | 9 | 10 | 10 | 10 | 10 | 11 |
| #200 | 9.4 | 7.8 | 9.2 | 7.9 | 8.7 | 8.7 | 9.5 |
| Design AC | 6.4 | 6.4 | 6.3 | 6.4 | 6.3 | 6.4 | 6.4 |
| Extracted AC | | 6.1 | 5.9 | 6.2 | 6.1 | 5.9 | 6.3 |
| Gmm ("D") | 2.48 | 2.48 | 2.47 | 2.46 | 2.46 | 2.48 | 2.48 |
| Gmb ("d") | 2.38 | 2.38 | 2.34 | 2.37 | 2.39 | 2.38 | 2.4 |
| Voids | 3.3 | 3.8 | 5.3 | 3.5 | 2.9 | 3.8 | 2.9 |

Table 6 cont.

All marshall data were 50 blow specimens compacted at 325F
NA= Extraction only, no marshall tests

Test Results
Mixture Properties
District 2- McCarthy Improvements

| Sieve | Mix | 09/08/93 | 09/08/93 | 09/15/93 | 09/16/93 | 09/17/93 | 09/20/93 |
|---|---|---|---|---|---|---|---|
| Size | Design | | | | | | |
| | | Sample 1 | Sample 2 | Sample 1 | Sample 1 | Sample 1 | Sample 1 |
| | | | | | | | |
| 3/4 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1/2 | 98 | 99 | 99 | 98 | 99 | 99 | 98 |
| 3/8 | 81 | 86 | 82 | 84 | 84 | 82 | 82 |
| #4 | 38 | 49 | 39 | 40 | 37 | 37 | 38 |
| #8 | 27 | 36 | 26 | 25 | 24 | 25 | 26 |
| #16 | 17 | 21 | 16 | 16 | 17 | 18 | 18 |
| #30 | 12 | 15 | 12 | 12 | 14 | 14 | 14 |
| #50 | 10 | 12 | 11 | 11 | 12 | 13 | 12 |
| #100 | 9 | 11 | 10 | 10 | 11 | 11 | 11 |
| #200 | 8 | 8.7 | 8.2 | 8.2 | 9.2 | 9.1 | 8.7 |
| Design AC | 6.1 | 6.1 | 6.1 | 6.1 | 6.1 | 6.1 | 6.1 |
| Extracted AC | | 6.2 | 6.1 | 6.1 | 6.2 | 6.2 | NA |
| Gmm ("D") | 2.5 | 2.49 | 2.49 | 2.49 | 2.5 | 2.5 | NA |
| Gmb ("d") | 2.44 | 2.44 | 2.42 | 2.41 | 2.4 | 2.44 | NA |
| Voids | 2.1 | 2.3 | 3.1 | 3.5 | 3.6 | 2.7 | NA |

Table 7

All marshall data were 50 blow specimens compacted at 325F
NA= Extraction only, no marshall tests

| Sieve | Mix | 10/04/93 | 10/05/93 | 10/06/93 | 10/07/93 |
|---|---|---|---|---|---|
| Size | Design | | | | |
| | | Sample 1 | Sample 1 | Sample 1 | Sample 1 |
| | | | | | |
| 3/4 | 100 | 100 | 100 | 100 | 100 |
| 1/2 | 98 | 99 | 100 | 99 | 100 |
| 3/8 | 81 | 84 | 81 | 84 | 99 |
| #4 | 38 | 40 | 36 | 35 | 82 |
| #8 | 27 | 26 | 24 | 24 | 39 |
| #16 | 17 | 18 | 17 | 16 | 26 |
| #30 | 12 | 14 | 14 | 12 | 18 |
| #50 | 10 | 12 | 12 | 10 | 14 |
| #100 | 9 | 11 | 11 | 9 | 12 |
| #200 | 8 | 8.4 | 9.4 | 7.6 | 11 |
| Design AC | 6.1 | 6.1 | 6.1 | 6.1 | 6.1 |
| Extracted AC | | 6.3 | 6 | 6.1 | 6.1 |
| Gmm ("D") | 2.5 | 2.51 | 2.51 | NA | NA |
| Gmb ("d") | 2.44 | 2.42 | 2.42 | NA | NA |
| Voids | 2.1 | 3.3 | 3.6 | NA | NA |

Table 7 cont.

All marshall data were 50 blow specimens compacted at 325F
NA= Extraction only, no marshall tests

Test Results
Mixture Properties
District 1- Gallagher Asphalt

| Sieve Size | Mix Design | 06/15/94 Sample 1 | 06/15/94 Sample 2 | 06/15/94 Sample 3 | 06/15/94 Sample 4 | 06/15/94 Sample 5 | 06/15/94 Sample 6 |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| 3/4 | 100 | 99 | 100 | 100 | 100 | 100 | 100 |
| 1/2 | 87 | 84 | 90 | 89 | 88 | 90 | 91 |
| 3/8 | 70 | 67 | 67 | 70 | 61 | 68 | 71 |
| #4 | 29 | 36 | 34 | 34 | 30 | 35 | 37 |
| #8 | 22 | 25 | 24 | 25 | 23 | 25 | 26 |
| #16 | 16 | 18 | 19 | 20 | 19 | 20 | 20 |
| #30 | 13 | 14 | 16 | 16 | 16 | 17 | 16 |
| #50 | 11 | 13 | 14 | 14 | 14 | 14 | 14 |
| #100 | 10 | 11 | 13 | 12 | 13 | 13 | 13 |
| #200 | 8.1 | 9.6 | 11.2 | 10.5 | 11 | 11 | 10.6 |
| Design AC | 6.2 | 6.2 | 6.2 | 6.2 | 6.2 | 6.2 | 6.2 |
| Extracted AC | | 5.7 | 6.1 | 6.2 | 6 | 6.5 | 6.3 |
| Gmm ("D") | 2.49 | 2.5 | 2.49 | NA | NA | NA | NA |
| Gmb ("d") | 2.4 | 2.4 | 2.39 | NA | NA | NA | NA |
| Voids | 3.5 | 4.7 | 4 | NA | NA | NA | NA |

Table 8

All marshall data were 50 blow specimens compacted at 325F
NA= Extraction only, no marshall tests

| Sieve Size | Mix Design | 06/16/94 Sample 1 | 06/24/94 Sample 1 | 06/28/94 Sample 1 | 07/05/94 Sample 1 | 07/06/94 Sample 1 | 06/15/94 Sample 1 |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| 3/4 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1/2 | 87 | 82 | 90 | 88 | 89 | 90 | 92 |
| 3/8 | 70 | 64 | 69 | 68 | 69 | 63 | 71 |
| #4 | 29 | 28 | 28 | 30 | 31 | 29 | 32 |
| #8 | 22 | 21 | 21 | 21 | 22 | 21 | 21 |
| #16 | 16 | 16 | 16 | 17 | 18 | 17 | 17 |
| #30 | 13 | 13 | 13 | 14 | 14 | 14 | 13 |
| #50 | 11 | 12 | 11 | 12 | 12 | 12 | 12 |
| #100 | 10 | 11 | 10 | 11 | 11 | 11 | 10 |
| #200 | 8.1 | 9.3 | 8.5 | 9.5 | 9.4 | 8.7 | 8.7 |
| Design AC | 6.2 | 6.2 | 6.2 | 6.2 | 6.2 | 6.2 | 6.2 |
| Extracted AC | | 6.1 | 5.9 | 6.2 | 6.1 | 6.1 | 6.3 |
| Gmm ("D") | 2.49 | 2.48 | 2.48 | 2.48 | 2.47 | 2.48 | 2.48 |
| Gmb ("d") | 2.4 | 2.41 | 2.39 | 2.38 | 2.37 | 2.36 | 2.39 |
| Voids | 3.5 | 2.8 | 3.4 | 3.8 | 4.3 | 4.8 | 3.7 |

Table 8 cont.

All marshall data were 50 blow specimens compacted at 325F
NA= Extraction only, no marshall tests

Test Results
Mixture Properties
District 8-Maclair Asphalt

| Sieve Size | Mix Design | 07/05/94 | 07/14/94 | 07/14/94 | 07/15/94 | 07/15/94 |
|---|---|---|---|---|---|---|
| | | Sample 1 | Sample 1 | Sample 2 | Sample 1 | Sample 2 |
| | | | | | | |
| 3/4 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1/2 | 86 | 94 | 87 | 88 | 88 | 86 |
| 3/8 | 57 | 63 | 61 | 59 | 62 | 54 |
| #4 | 29 | 26 | 31 | 30 | 29 | 25 |
| #8 | 18 | 14 | 19 | 19 | 17 | 16 |
| #16 | 14 | 10 | 15 | 15 | 14 | 13 |
| #30 | 12 | 9 | 13 | 13 | 13 | 12 |
| #50 | 11 | 8 | 13 | 12 | 12 | 11 |
| #100 | 10 | 7 | 12 | 11 | 11 | 11 |
| #200 | 8.7 | 6.4 | 10.1 | 9.5 | 9.3 | 9 |
| Design AC | 7 | 7 | 7 | 7 | 7 | 7 |
| Extracted AC | | 6.3 | 7.2 | 6.9 | 7 | 6.7 |
| Gmm ("D") | 2.4 | 2.41 | 2.42 | 2.4 | 2.44 | 2.42 |
| Gmb ("d") | 2.31 | 2.17 | 2.27 | 2.28 | 2.24 | 2.24 |
| Voids | 2.4 | 9.8 | 6.2 | 4.9 | 8.4 | 7.5 |

Table 9

All marshall data were 50 blow specimens compacted at 325F
NA= Extraction only, no marshall tests

Test Results
Mixture Properties
## District 3-Azzarelli Construction

| Sieve Size | Mix Design | 07/26/94 | 07/26/94 | 08/05/94 | 08/05/94 | 08/11/94 |
|---|---|---|---|---|---|---|
| | | Sample 1 | Sample 2 | Sample 1 | Sample 2 | Sample 1 |
| | | | | | | |
| 3/4 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1/2 | 91 | 96 | 91 | 94 | 94 | 93 |
| 3/8 | 73 | 82 | 72 | 76 | 77 | 78 |
| #4 | 32 | 37 | 31 | 38 | 37 | 38 |
| #8 | 21 | 22 | 18 | 22 | 21 | 22 |
| #16 | 16 | 17 | 13 | 17 | 17 | 17 |
| #30 | 13 | 14 | 12 | 15 | 15 | 15 |
| #50 | 12 | 13 | 11 | 14 | 13 | 14 |
| #100 | 11 | 13 | 10 | 13 | 13 | 13 |
| #200 | 9.6 | 10.9 | 8.6 | 11.5 | 11.3 | 11.4 |
| Design AC | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 |
| Extracted AC | | 6.3 | 6.1 | 6.2 | 6 | 6.1 |
| Gmm ("D") | 2.46 | 2.46 | 2.47 | 2.46 | 2.46 | 2.47 |
| Gmb ("d") | 2.38 | 2.38 | 2.43 | 2.37 | 2.36 | 2.39 |
| Voids | 3.3 | 3.2 | 5.3 | 3.8 | 4 | 3 |

Table 10

All marshall data were 50 blow specimens compacted at 325F
NA= Extraction only, no marshall tests

**Steel Slag CM00 Gradation Requirements**

| Sieve | Percent Passing |
|---|---|
| 3/4 inch | 100 |
| 1/2 inch | $85 \pm 5$ |
| 3/8 inch | $55 \pm 10$ |
| No. 4 | $6 \pm 6$ |

Table 11

## Hamburg WTD Results

| Core | Project | Hamburg WTD Results |
|---|---|---|
| 1 | District 6 - IL 24 | 1 mm at 20,000 passes |
| 2 | District 6 - U.S. 36 | 20 mm at 17,500 passes |
| 3 | District 2 - I-80 | 20 mm at 10,500 passes |
| 4 | District 3 - I-57 (flushed area) | Rapid Failure[a] |
| 6 | District 3 - I-57 (flushed area) | Rapid Failure[a] |
| 5 | District 3 - I-57 | 5.4 mm at 20,000 passes |
| 7 | District 3 - I-57 | 6.9 mm at 20,000 passes |
| 8 | District 8 - I-55 (flushed area) | Rapid Failure[b] |
| 10 | District 8 - I-55 (flushed area) | Rapid Failure[b] |
| 9 | District 8 - I-55 | Rapid Failure[c] |
| 11 | District 8 - I-55 | Rapid Failure[c] |
| 12 | District 1 - IL 394 (Cracked Specimen) | Not Tested |
| 13 | District 1 - IL 394 | 8.8 mm at 20,000 passes |
| 14 | District 1 - IL 394 | 8.9 mm at 20,000 passes |

Table 12

[a] Terminated at 8,700 passes

[b] Terminated at 3,800 passes

[c] Terminated at 7,000 passes

Hot-Mix Asphalt

Stone Matrix Asphalt

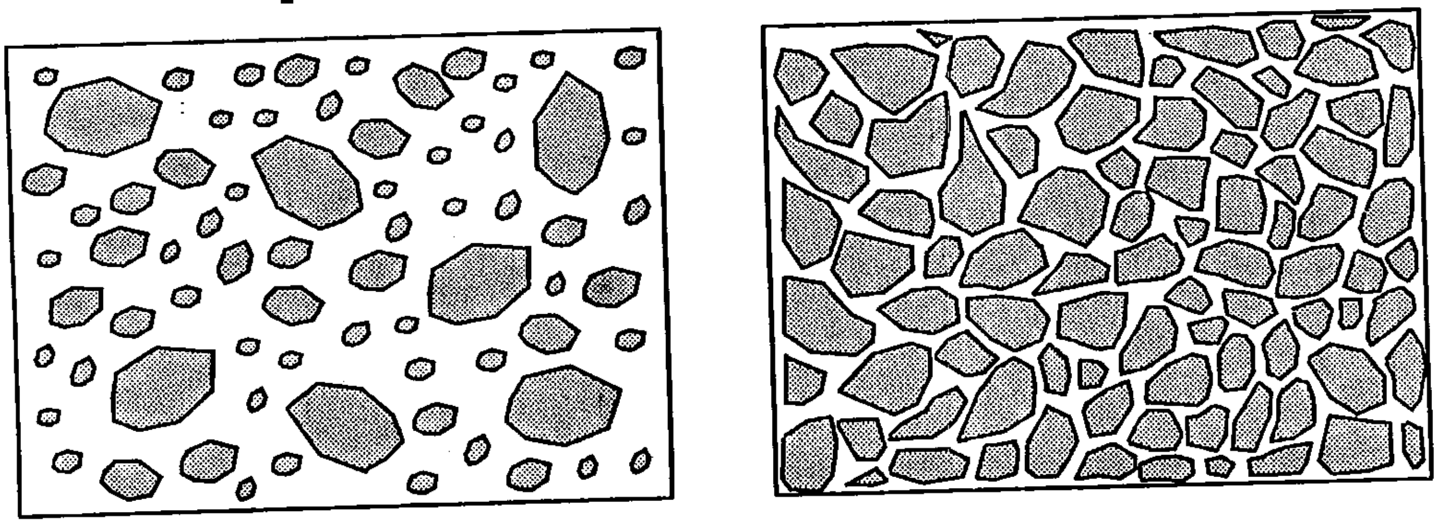
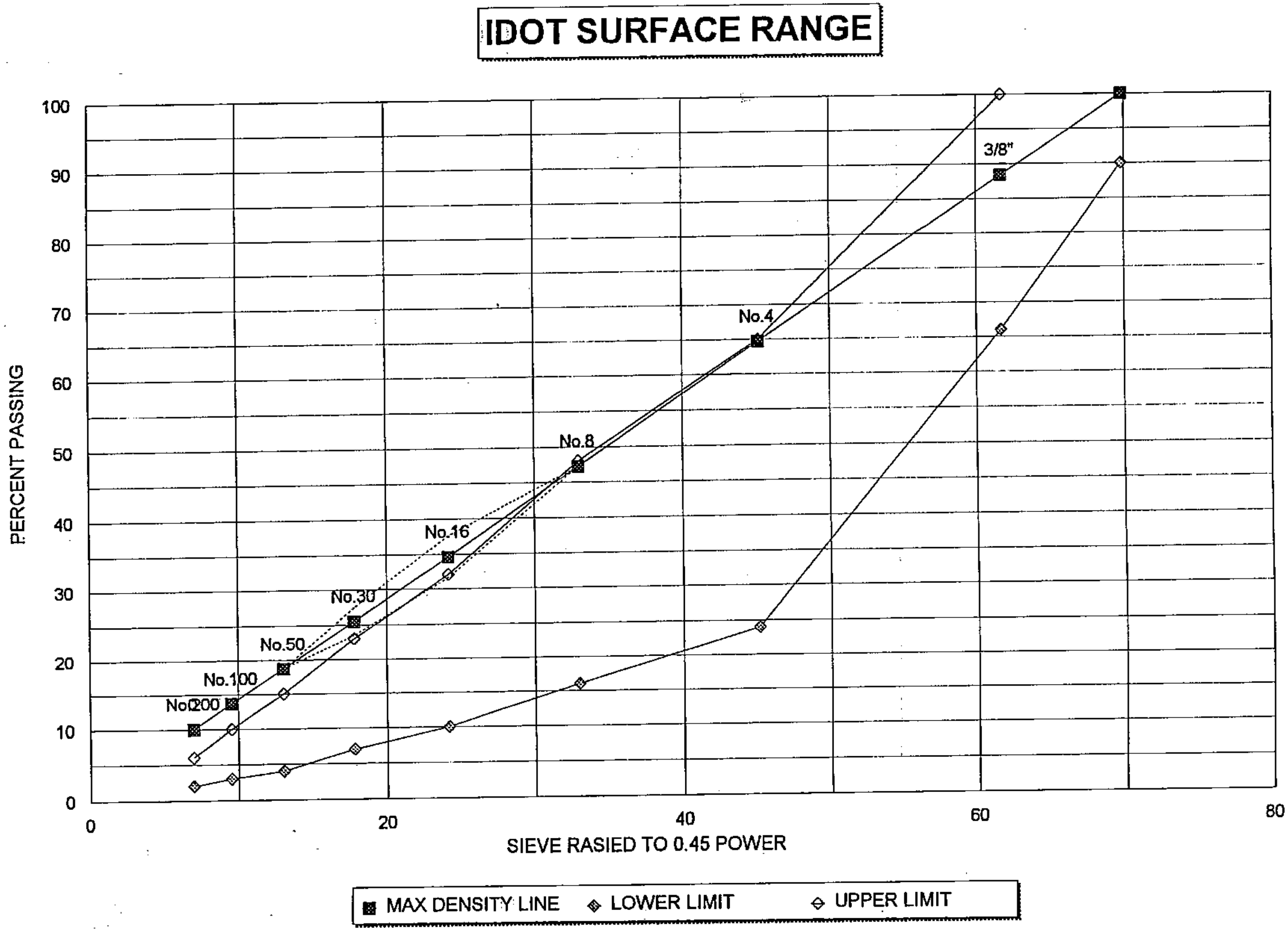


Figure 1



IDOT SURFACE RANGE
PERCENT PASSING
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
SIEVE RASIED TO 0.45 POWER
No.200
No.100
No.50
No.30
No.16
No.8
No.4
3/8"
MAX DENSITY LINE
LOWER LIMIT
UPPER LIMIT


Figure 2

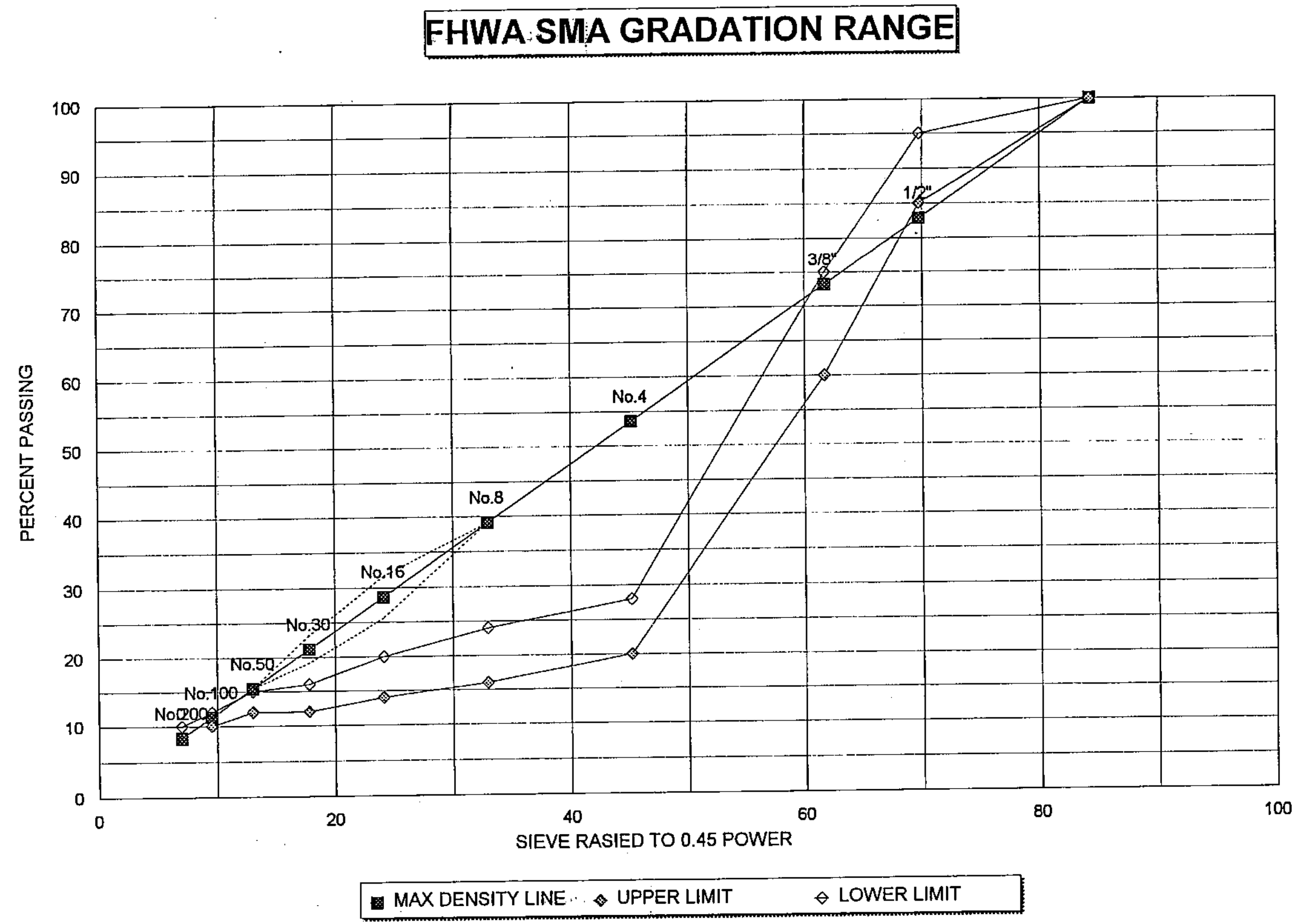

FHWA SMA GRADATION RANGE
PERCENT PASSING
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
SIEVE RASIED TO 0.45 POWER
1/2"
3/8"
No.4
No.8
No.16
No.30
No.50
No.100
No.200
MAX DENSITY LINE
UPPER LIMIT
LOWER LIMIT

Figure 3

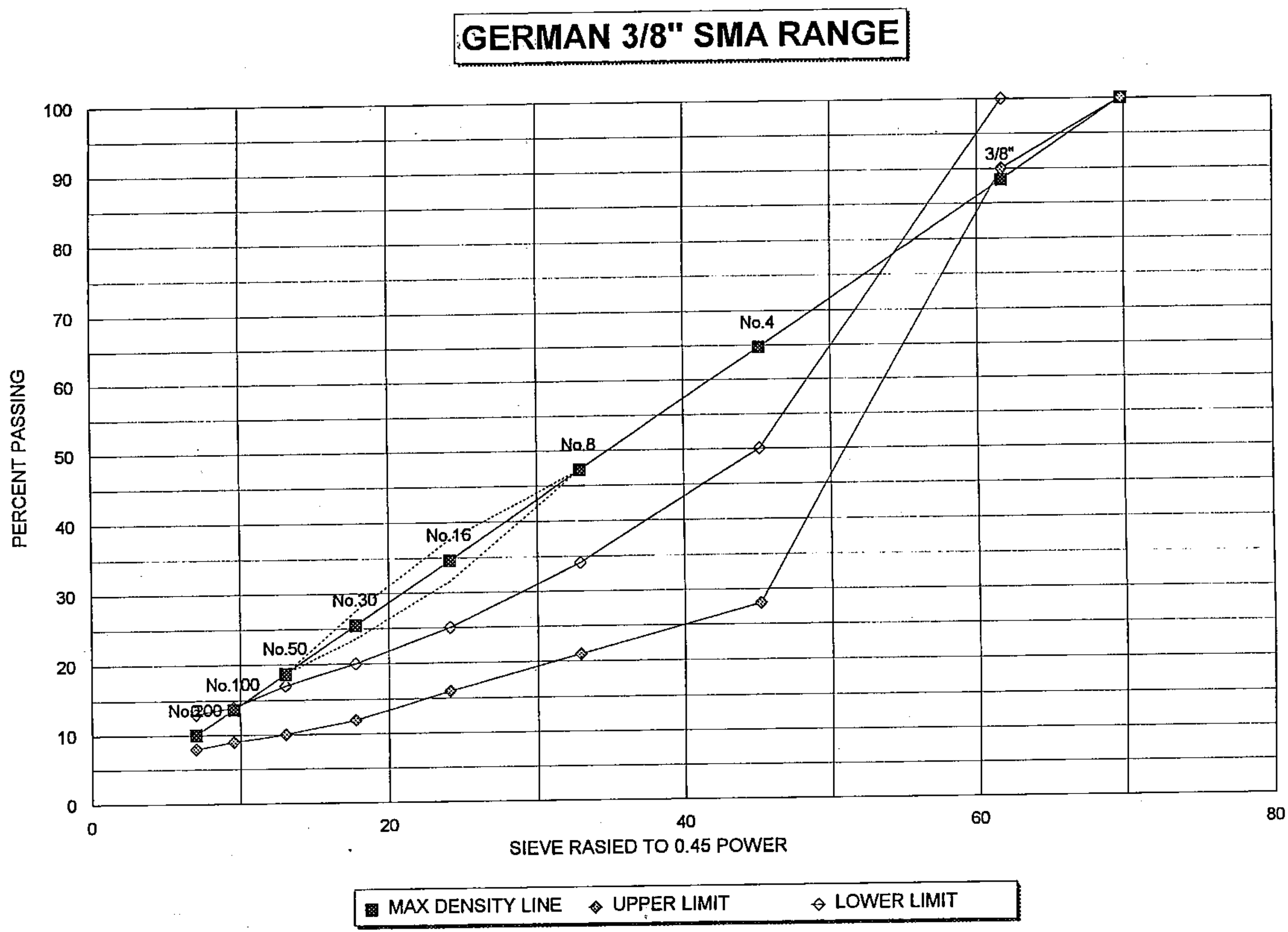

GERMAN 3/8" SMA RANGE
PERCENT PASSING
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
SIEVE RASIED TO 0.45 POWER
3/8"
No.4
No.8
No.16
No.30
No.50
No.100
No.200
MAX DENSITY LINE
UPPER LIMIT
LOWER LIMIT

Figure 4

**APPENDIX A**

NATIONAL CENTER FOR
ASPHALT TECHNOLOGY
211 Ramsay Hall
AUBURN UNIVERSITY, AL 36849-5354

August 3, 1992

Mr. J.G. Gehler. P.E.
Engineer of Materials and Physical Research
Illinois Department of Transportation
126 East Ash Street
Springfield, Illinois 62704-4766

Dear Jim:

The mix design for the SMA project has been completed. This mix design replaces the original mix design that was provided to you approximately one month ago. The original mix design was inadvertently performed on the aggregates as received. These aggregates were not rescreened to provide a gradation equal to that provided for the average of several tests results from the stockpiles.

The mix design reported herein was performed after rescreening the aggregate and reblending to meet the average gradation of the stockpiles. If you have any questions please let me know.

Sincerely,

Ray
E.R. Brown
Director

ERB:jw

Attachments



A PROJECT OF THE NAPA EDUCATION FOUNDATION AND AUBURN UNIVERSITY
205-844-6228 • FAX 205-844-6248

**SMA Mix Design for State of Illinois**

**August 1992**

A mix design for the Stone Matrix Asphalt (SMA) project in Illinois has been completed by NCAT. The mix design was performed using 50-blows with the mechanical marshall hammer.

Four aggregates were received and used in this project. The aggregates were identified as 1/2 - 3/8, 3/8 - 16, minus No. 4, and filler. The gradation of each of these aggregates is shown in Table 1. The gradation of each stockpile was provided to NCAT by the Illinois DOT and were based on a number of earlier tests conducted on the stockpiles. The aggregates received did not meet these gradations but they were separated into sizes and blended to meet the gradations shown in Table 1. It was determined that the percent of each aggregate to be used in the mix design was:

| Aggregate | Percent used |
|---|---|
| 1/2-3/8 | 65 |
| 3/8-16 | 15 |
| Minus No. 4 | 11 |
| Filler | 9 |

The gradation determined using these percentages is shown Table 1 and plotted in Figure 1.

Samples of the SMA mixture were prepared at asphalt contents of 5.0, 5.5, 6.0, 6.5, and 7.0 percent and compacted with 50-blows of Marshall compactor. Samples were then evaluated for mix properties (Table 2). The asphalt cement used in this mix design was a Styrelf modified AC provided to NCAT by the Illinois DOT.

The data for unit weight, stability, flow, voids in total mix, and voids in mineral aggregate were plotted in Figures 2-6. The optimum asphalt content for SMA mixes is normally selected at 3.0% voids or slightly higher voids, The plot in Figure 2 shown that an asphalt content of 6.2% provides 3.0% voids. The optimum asphalt content was selected at 6.0% however since the voids normally tend to close slightly in plant mixed materials. The 6.0% asphalt content is only a starting point and this should be adjusted as needed during construction to control the laboratory voids at

3% or slightly higher. The optimum asphalt content for SMA should be approximately 6.0 percent or higher.

The unit weight data is shown on Figure 3. The optimum asphalt content of 6.0% is on the down side of the unit weight curve. This has been typical of SMA mixes, however, for dense graded HMA the optimum asphalt content is typically near the peak of the curve or even before the peak.

The voids in the mineral aggregate (VMA) data is shown on Figure 4. The optimum asphalt content is on the up side of the curve which again is typical of SMA. The VMA for SMA mixes should be approximately 17.0 or higher. This SMA mixture has a VMA of 17.1 at 6.0% asphalt content. Typically the optimum asphalt content for dense graded mixes is near the low point of the VMA curve. This is not true with SMA mixtures.

The stability and flow data are shown for information only (Figures 5-6). These properties should not be specified for SMA mixes. The stability values for SMA are typically lower than that for dense graded mixes and the flow values for SMA mixes are typically higher than that for dense graded mixes.

Based on the results of this mix design, this appears to be a satisfactory SMA. As with other SMA mixes, it is sensitive to changes in gradations. For example, a 5% change in the percent passing the No. 4 Sieve is likely to change the optimum asphalt content by 1.0% or more. This is typical of SMA mixes. SMA mixes, however, are not very sensitive to changes in asphalt content. For example, Figure 2 shows that 2.5-3.5 percent voids will be produced over a range of asphalt contents from 5.4-6.8 percent.

**Table 1. Aggregate Gradation**

| Sieve Size | 1/2 - 3/8 | 3/8 - 16 | Minus No. 4 | Filler | JMF Blend |
|---|---|---|---|---|---|
| 3/4 inch | 100 | 100 | 100 | 100 | 100 |
| 1/2 inch | 97 | 100 | 100 | 100 | 98 |
| 3/8 inch | 52 | 99 | 100 | 100 | 69 |
| No. 4 | 6 | 31 | 99 | 100 | 28 |
| No. 8 | 5 | 18 | 83 | 100 | 24 |
| No. 16 | 4 | 4 | 53 | 100 | 18 |
| No. 30 | 3 | 3 | 32 | 99 | 15 |
| No. 50 | 3 | 3 | 15 | 98 | 13 |
| No. 100 | 3 | 3 | 6 | 97 | 12 |
| No. 200 | 3.0 | 3.0 | 3.0 | 77.0 | 9.7 |

*Table 2*

NATIONAL CENTER FOR ASPHALT TECHNOLOGY (NCAT)

# HOT MIX ASPHALT PROPERTIES

JOB NUMBER:
PROJECT: IL DOT
BLEND DESCRIPTION MIX 1 MIX DESIGN 65% (1/2-3/8) 15% (3/8-16) 11% (-4) 9% (FILLER)
DATE: 7/24/92

AC Sp. Gr. (Gb) = 1.03
Effective Sp. Gr. of Aggregate (Gse) = 2.697
Bulk Sp. Gr. of Aggregate (Gsb) =

| Specimen Number | Asphalt Content (%) | Average Thickness (Inches) | WEIGHTS: In Air (gm) | WEIGHTS: In Water (gm) | WEIGHTS: SSD (gm) | MIX VOLUMES: Volume (cc) | MIX VOLUMES: Volume Correlation Ratio | SPECIFIC GRAVITIES: Bulk (Gmb) | SPECIFIC GRAVITIES: TMD (Gmm) | VOLUMES: Aggregate Volume (cc) | VOLUMES: AC by Volume (%) | Unit Weight (pcf) | VOIDS: Total (%) | VOIDS: VMA (%) | VOIDS: Filled (%) | STABILITY: Measured (lb) | STABILITY: Corrected (lb) | Flow (.01 in) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S |
| | | | | | | (F-E) | | D / (F-E) | | (100-B) x I / (Gse) | B x I / (Gb) | (I x 62.4) | 100(1-I/J) | (100-K) | 100(O-N) / O | | (H x Q) | |
| 5.0 1 | 5.0 | 2.495 | 1198.7 | 704.3 | 1200.6 | 496.3 | 1.04 | 2.415 | 2.494 | 85.1 | 11.7 | 150.7 | 3.2 | 14.9 | 78.8 | 1859 | 1933 | 17 |
| 5.0 2 | 5.0 | 2.607 | 1225.6 | 714.6 | 1228.3 | 513.7 | 1.00 | 2.386 | 2.494 | 84.0 | 11.6 | 148.9 | 4.3 | 16.0 | 72.8 | 1675 | 1675 | 15 |
| 5.0 3 | 5.0 | 2.602 | 1220.7 | 710.0 | 1223.8 | 513.8 | 1.00 | 2.376 | 2.494 | 83.7 | 11.5 | 148.3 | 4.7 | 16.3 | 71.0 | 1695 | 1695 | 17 |
| AVG | | | | | | 507.9 | | 2.392 | | 84.3 | 11.6 | 149.3 | 4.1 | 15.7 | 74.2 | 1743 | 1768 | 16 |
| 5.5 1 | 5.5 | 2.543 | 1194.2 | 697.4 | 1196.4 | 499.0 | 1.04 | 2.393 | 2.476 | 83.9 | 12.8 | 149.3 | 3.3 | 16.1 | 79.3 | 1350 | 1404 | 14 |
| 5.5 2 | 5.5 | 2.491 | 1196.7 | 698.0 | 1198.4 | 500.4 | 1.04 | 2.391 | 2.476 | 83.8 | 12.8 | 149.2 | 3.4 | 16.2 | 78.9 | 1473 | 1532 | 16 |
| 5.5 3 | 5.5 | 2.588 | 1224.4 | 714.2 | 1226.8 | 512.6 | 1.00 | 2.389 | 2.476 | 83.7 | 12.8 | 149.0 | 3.5 | 16.3 | 78.4 | 1450 | 1450 | 18 |
| AVG | | | | | | 504.0 | | 2.391 | | 83.8 | 12.8 | 149.2 | 3.4 | 16.2 | 78.9 | 1424 | 1462 | 16 |
| 6.0 1 | 6.0 | 2.583 | 1222.0 | 709.0 | 1224.3 | 515.3 | 1.00 | 2.371 | 2.458 | 82.7 | 13.8 | 148.0 | 3.5 | 17.3 | 79.7 | 1413 | 1413 | 14 |
| 6.0 2 | 6.0 | 2.590 | 1220.4 | 711.8 | 1222.9 | 511.1 | 1.00 | 2.388 | 2.458 | 83.2 | 13.9 | 149.0 | 2.9 | 16.8 | 83.0 | 1293 | 1293 | 17 |
| 6.0 3 | 6.0 | 2.610 | 1231.8 | 716.0 | 1233.8 | 517.8 | 1.00 | 2.379 | 2.458 | 82.9 | 13.9 | 148.4 | 3.2 | 17.1 | 81.2 | 1488 | 1488 | 16 |
| AVG | | | | | | 514.7 | | 2.379 | | 82.9 | 13.9 | 148.5 | 3.2 | 17.1 | 81.3 | 1398 | 1398 | 16 |
| 6.5 1 | 6.5 | 2.620 | 1232.4 | 712.4 | 1233.8 | 521.4 | 1.00 | 2.364 | 2.440 | 81.9 | 14.9 | 147.5 | 3.1 | 18.1 | 82.7 | 1375 | 1375 | 18 |
| 6.5 2 | 6.5 | 2.590 | 1233.9 | 714.3 | 1235.5 | 521.2 | 1.00 | 2.367 | 2.440 | 82.1 | 14.9 | 147.7 | 3.0 | 17.9 | 83.4 | 1345 | 1345 | 19 |
| 6.5 3 | 6.5 | 2.612 | 1238.2 | 720.4 | 1240.0 | 519.6 | 1.00 | 2.383 | 2.440 | 82.6 | 15.0 | 148.7 | 2.3 | 17.4 | 86.6 | 1310 | 1310 | 19 |
| AVG | | | | | | 520.7 | | 2.371 | | 82.2 | 15.0 | 148.0 | 2.8 | 17.8 | 84.2 | 1343 | 1343 | 19 |
| 7.0 1 | 7.0 | 2.652 | 1245.4 | 720.0 | 1246.5 | 526.5 | 0.96 | 2.365 | 2.422 | 81.6 | 16.1 | 147.6 | 2.3 | 18.4 | 87.3 | 1370 | 1315 | 23 |
| 7.0 2 | 7.0 | 2.600 | 1229.3 | 711.4 | 1230.1 | 518.7 | 1.00 | 2.370 | 2.422 | 81.7 | 16.1 | 147.9 | 2.1 | 18.3 | 88.2 | 1550 | 1550 | 22 |
| 7.0 3 | 7.0 | 2.601 | 1227.4 | 709.6 | 1228.7 | 519.1 | 1.00 | 2.364 | 2.422 | 81.5 | 16.1 | 147.5 | 2.4 | 18.5 | 87.1 | 1445 | 1445 | 20 |
| AVG | | | | | | 521.4 | | 2.367 | | 81.6 | 16.1 | 147.7 | 2.3 | 18.4 | 87.6 | 1455 | 1437 | 22 |

Computed By:

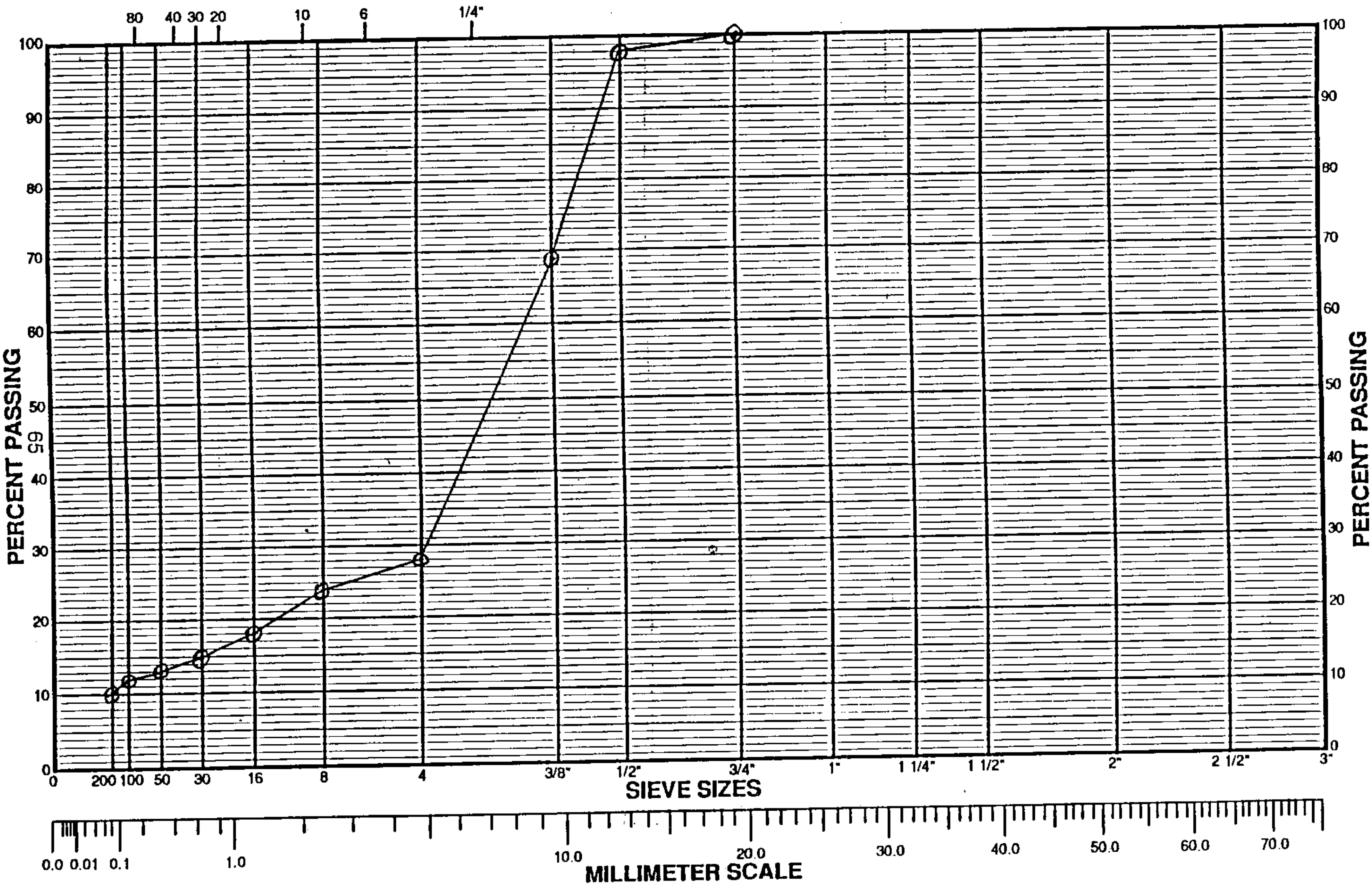
Checked By:

SSD = Saturated Surface Dry
Sp. Gr. = Specific Gravity
TMD = Theoretical Maximum Density
gm = gram
cc = cubic centimeter
AC = Asphalt Cement
pcf = pounds per cubic foot
in = inches
Gmb = Bulk Specific Gravity of Compacted Mix
Gmm = Theoretical Maximum Specific Gravity of Mix
Gsb = Bulk Specific Gravity of Aggregate
Gse = Effective Specific Gravity of Aggregate
Gb = Specific Gravity of Asphalt Cement

NCAT Form 100 Sep 91

Figure 1

# NATIONAL CENTER FOR ASPHALT TECHNOLOGY (NCAT)
# GRADATION CHART
## SIEVE SIZES RAISED TO 0.45 POWER




Maximum Density Gradation = Straight Line Connecting Percentage Point Passing Maximum Nominal Sieve And 0% Passing No. 0 Sieve.

Figure 2

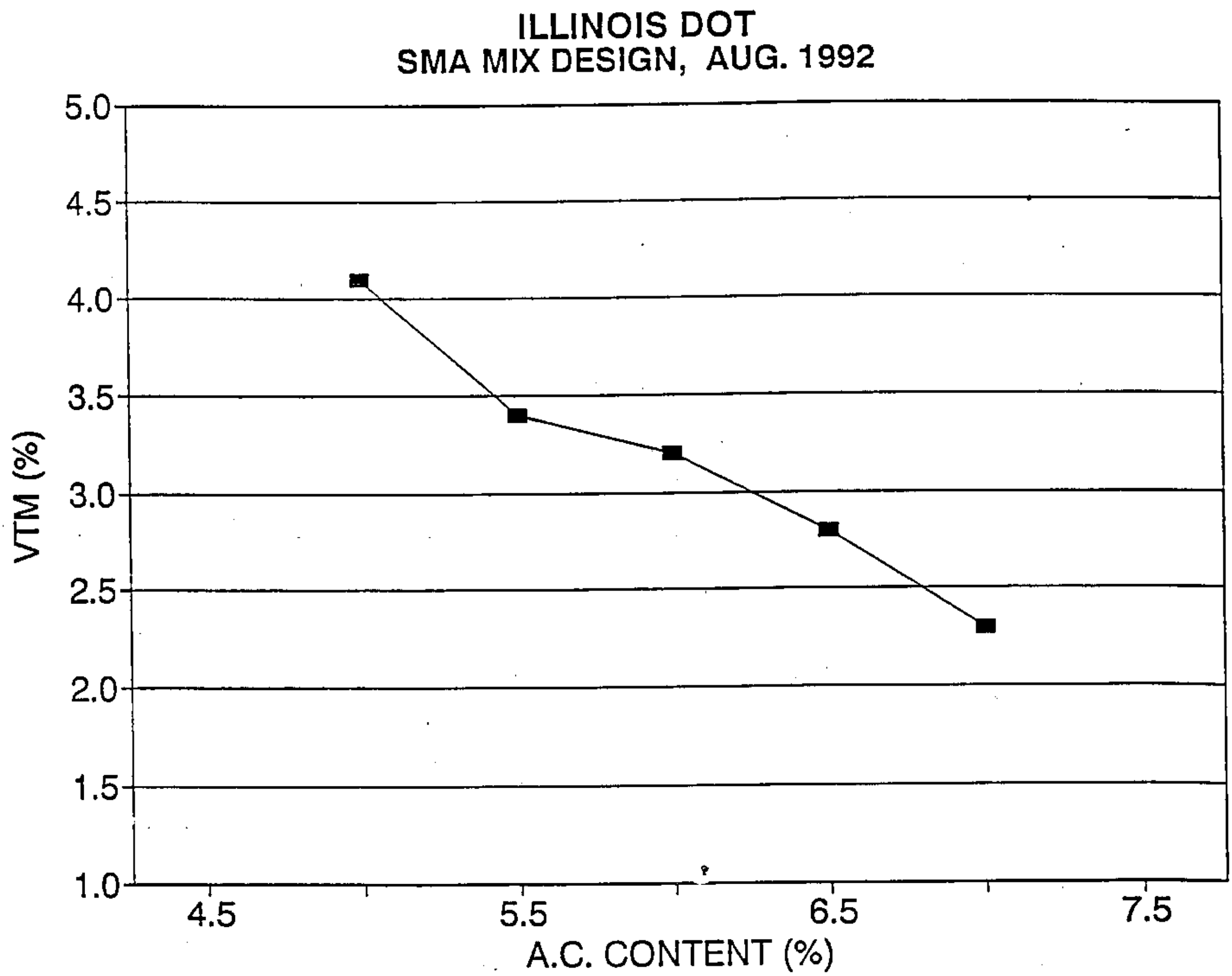
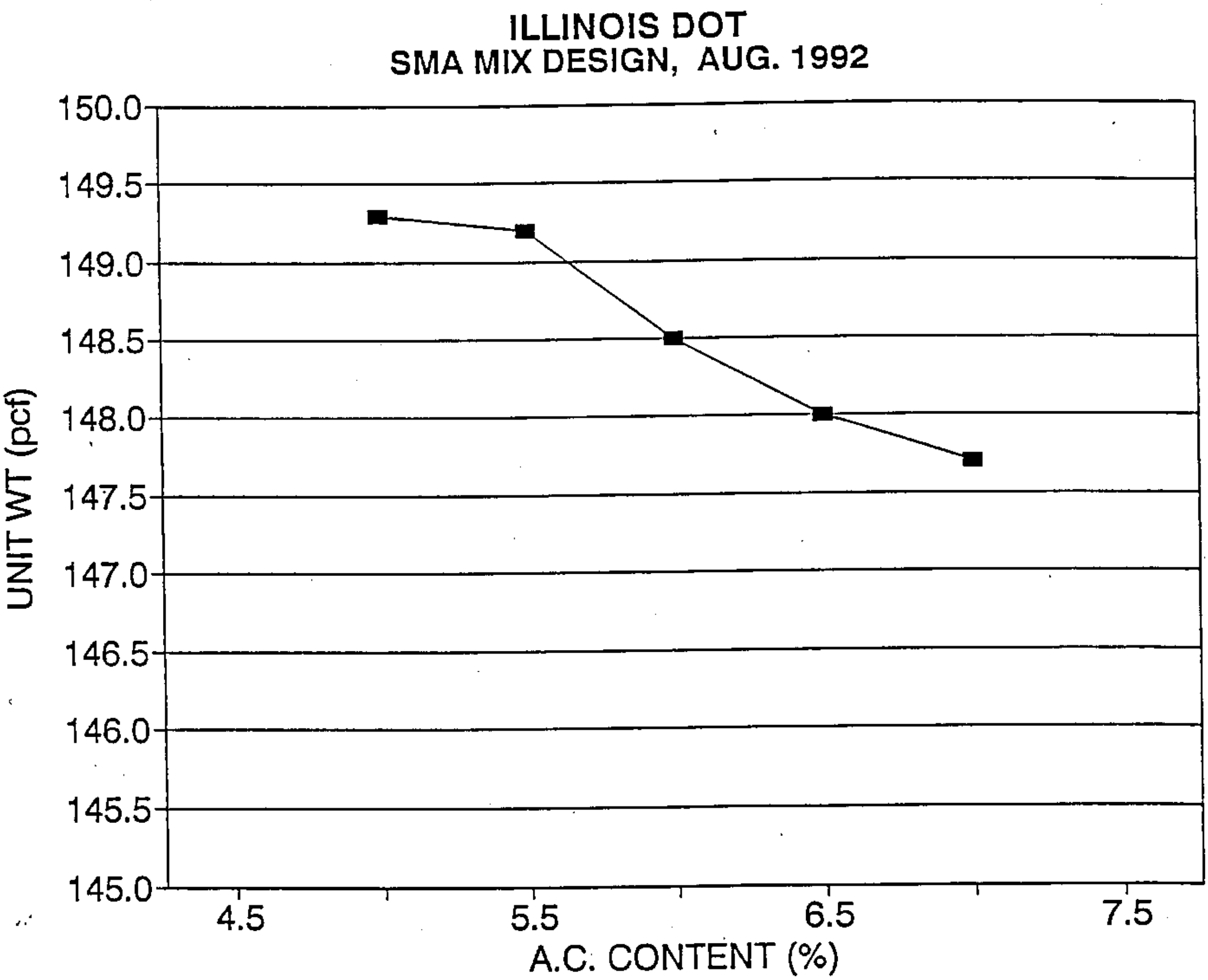
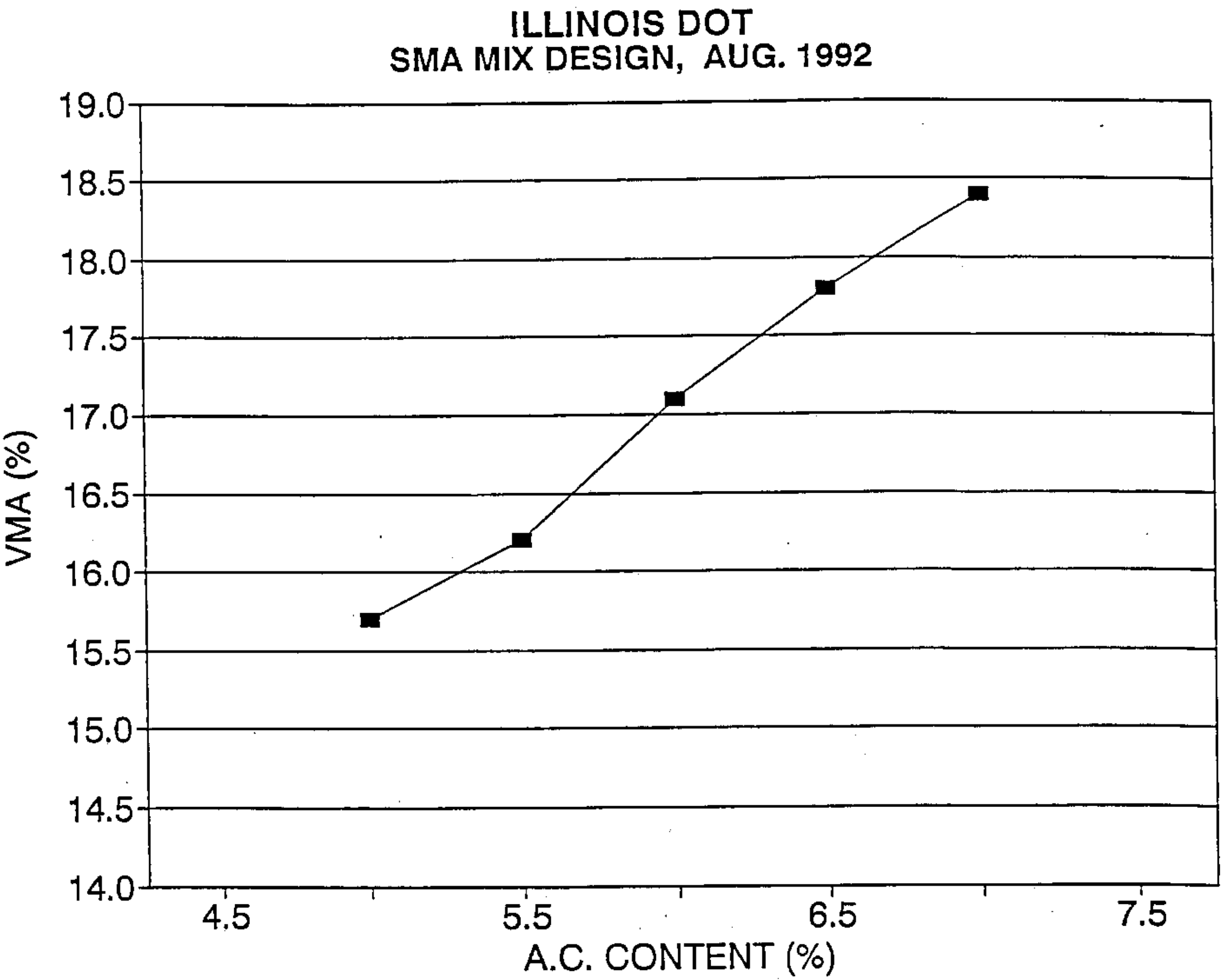

ILLINOIS DOT
SMA MIX DESIGN, AUG. 1992
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
VTM (%)
4.5
5.5
6.5
7.5
A.C. CONTENT (%)

Figure 3



ILLINOIS DOT
SMA MIX DESIGN, AUG. 1992
UNIT WT (pcf)
150.0
149.5
149.0
148.5
148.0
147.5
147.0
146.5
146.0
145.5
145.0
4.5
5.5
6.5
7.5
A.C. CONTENT (%)

Figure 4



ILLINOIS DOT
SMA MIX DESIGN, AUG. 1992
19.0
18.5
18.0
17.5
17.0
16.5
16.0
15.5
15.0
14.5
14.0
VMA (%)
4.5
5.5
6.5
7.5
A.C. CONTENT (%)

Figure 5

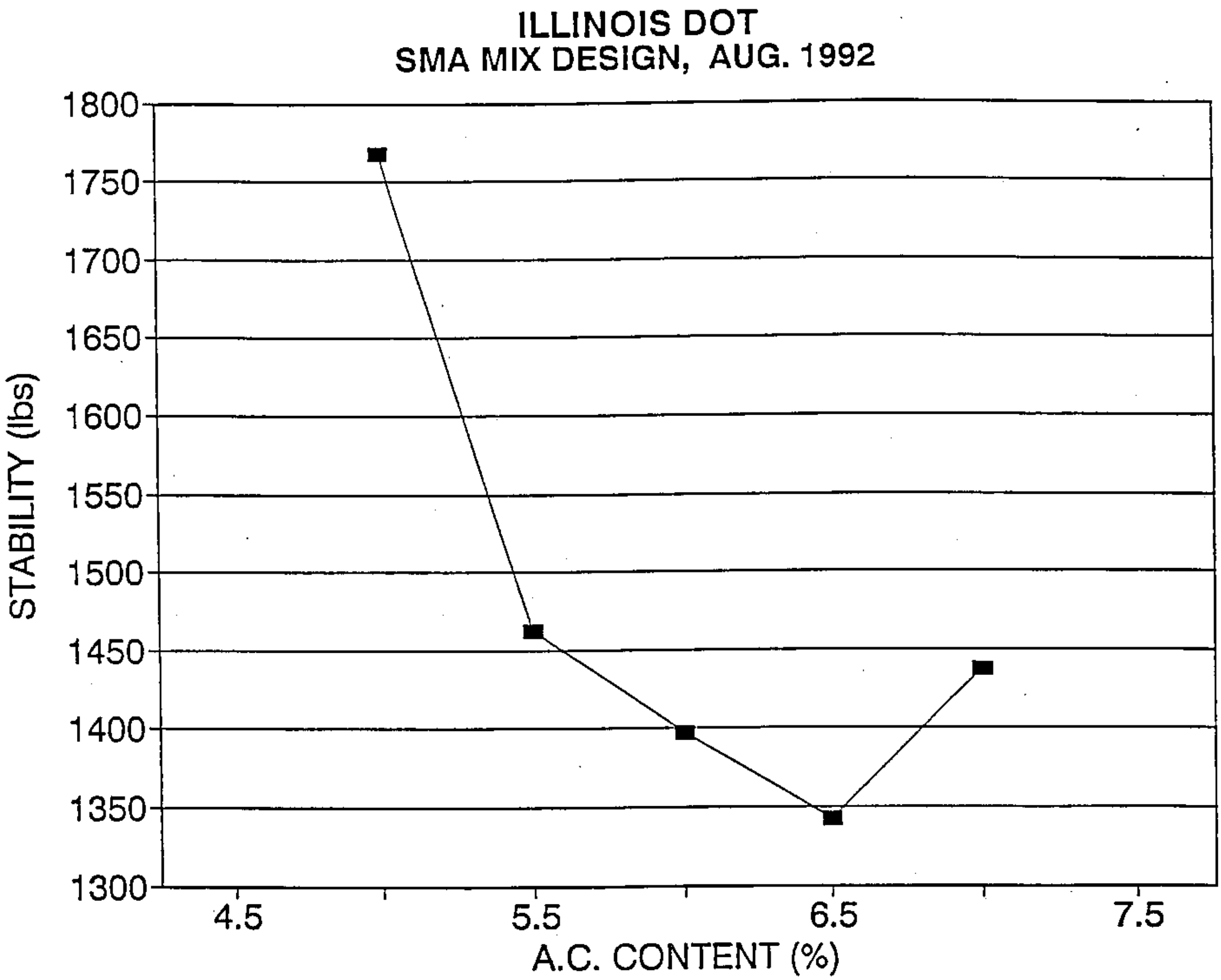
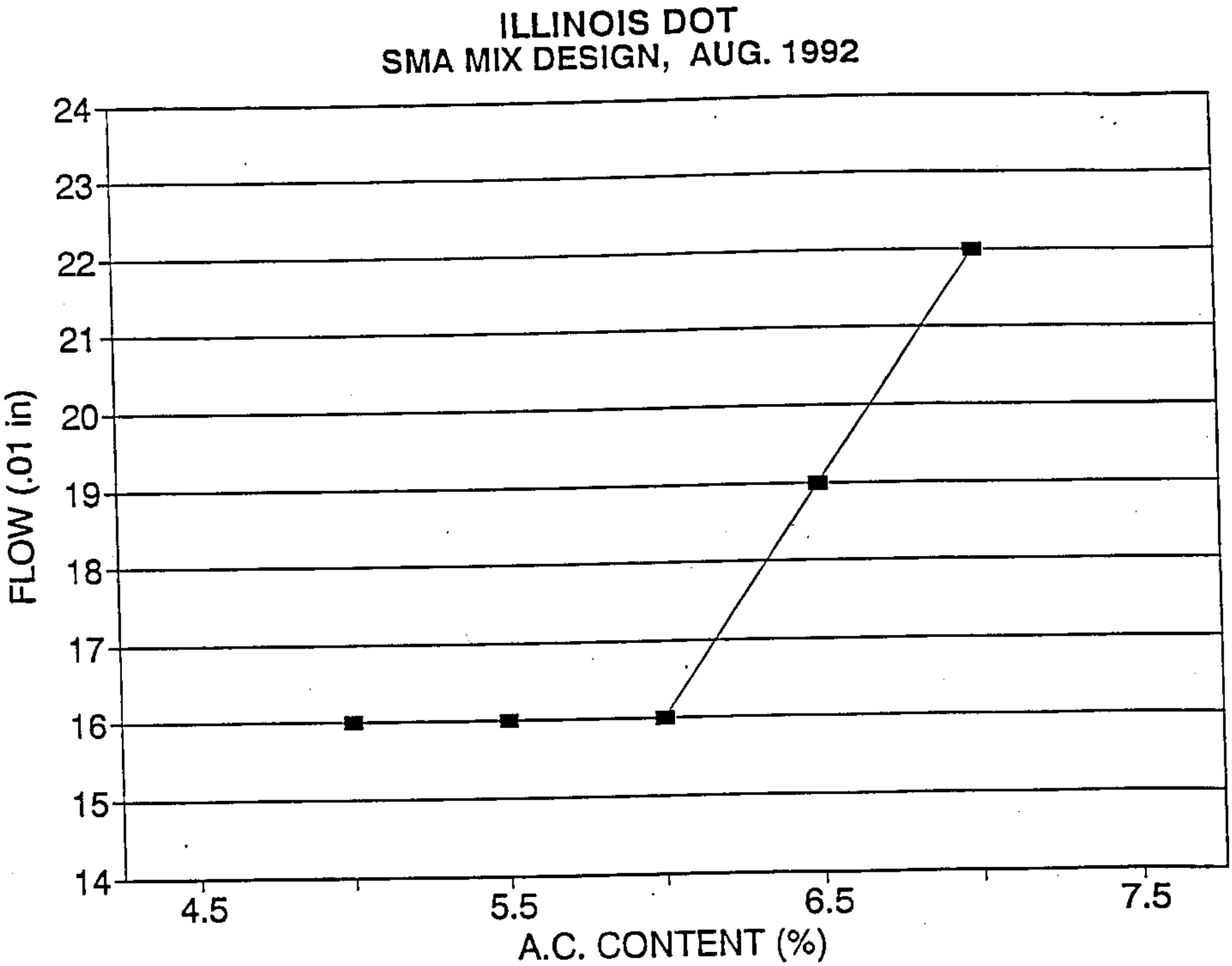

ILLINOIS DOT
SMA MIX DESIGN, AUG. 1992
STABILITY (lbs)
1800
1750
1700
1650
1600
1550
1500
1450
1400
1350
1300
4.5
5.5
6.5
7.5
A.C. CONTENT (%)

Figure 6



ILLINOIS DOT
SMA MIX DESIGN, AUG. 1992
24
23
22
21
20
19
18
17
16
15
14
FLOW (.01 in)
4.5
5.5
6.5
7.5
A.C. CONTENT (%)

## APPENDIX B

BDESIGNW
VERSION 1.3

IDOT - Bureau of Materials and Physical Research
Bituminous Mixture Design

DATE: 14-Aug-93

SEQ NO:

Design Number: 56BIT1336

Mixture Producer: SANKEY CONSTRUCTION ( 1738-01 )
Mixture: 1843201

| Agg No. | #1 | #2 | #3 | #4 | #5 | #6 | ASPHALT |
|---|---|---|---|---|---|---|---|
| Size | 032CA16 | 038FM21 | 31500C | 004MF02 | | | 10112 |
| Source (PROD#) | 50912-02 | 50912-02 | N/A | 1738-01 | | | 3913-02 |
| (NAME) | VULCAN | VULCAN | CENTRAL | SANKEY | | | MARATHON |
| (LOC) | | | FIBER | | | | |
| Aggregate Blend | 69.6 | 26.2 | 0.3 | 3.9 | | | 100.0 |

| Agg No. Sieve Size | #1 | #2 | #3 | #4 | #5 | #6 | Blend | Specifications Min | Max | FORMULA | FORMULA RANGE Min | Max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | | | 100 | | |
| 3/4 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | | | 100 | | |
| 1/2 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | | | 100 | | |
| 3/8 | 94.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 95.8 | 90 | 100 | 96 | | |
| #4 | 26.0 | 96.0 | 100.0 | 100.0 | 100.0 | 100.0 | 47.4 | 28 | 50 | 47 | | |
| #8 | 4.0 | 68.0 | 100.0 | 100.0 | 100.0 | 100.0 | 24.8 | 21 | 28 | 25 | | |
| #16 | 3.0 | 44.0 | 100.0 | 100.0 | 100.0 | 100.0 | 17.8 | | | 18 | | |
| #30 | 3.0 | 29.0 | 77.0 | 100.0 | 100.0 | 100.0 | 13.8 | 12 | 16 | 14 | | |
| #50 | 2.0 | 23.0 | 57.0 | 100.0 | 100.0 | 100.0 | 11.5 | 12 | 15 | 11 | | |
| #100 | 2.0 | 19.0 | 39.0 | 100.0 | 100.0 | 100.0 | 10.4 | | | 10 | | |
| #200 | 2.0 | 15.6 | 20.0 | 98.8 | 100.0 | 100.0 | 9.4 | 8 | 10 | 9.4 | | |

| | #1 | #2 | #3 | #4 | #5 | #6 | |
|---|---|---|---|---|---|---|---|
| Bulk Sp Gr | 2.633 | 2.668 | 1.13 | 2.701 | 1 | 1 | |
| Apparent Sp Gr | 2.791 | 2.744 | 1.13 | 2.701 | 1 | 1 | |
| Absorption, % | 2.2 | 1 | 0 | 0 | 0 | 0 | |
| | | | | | | SP GR AC | 1.037 |

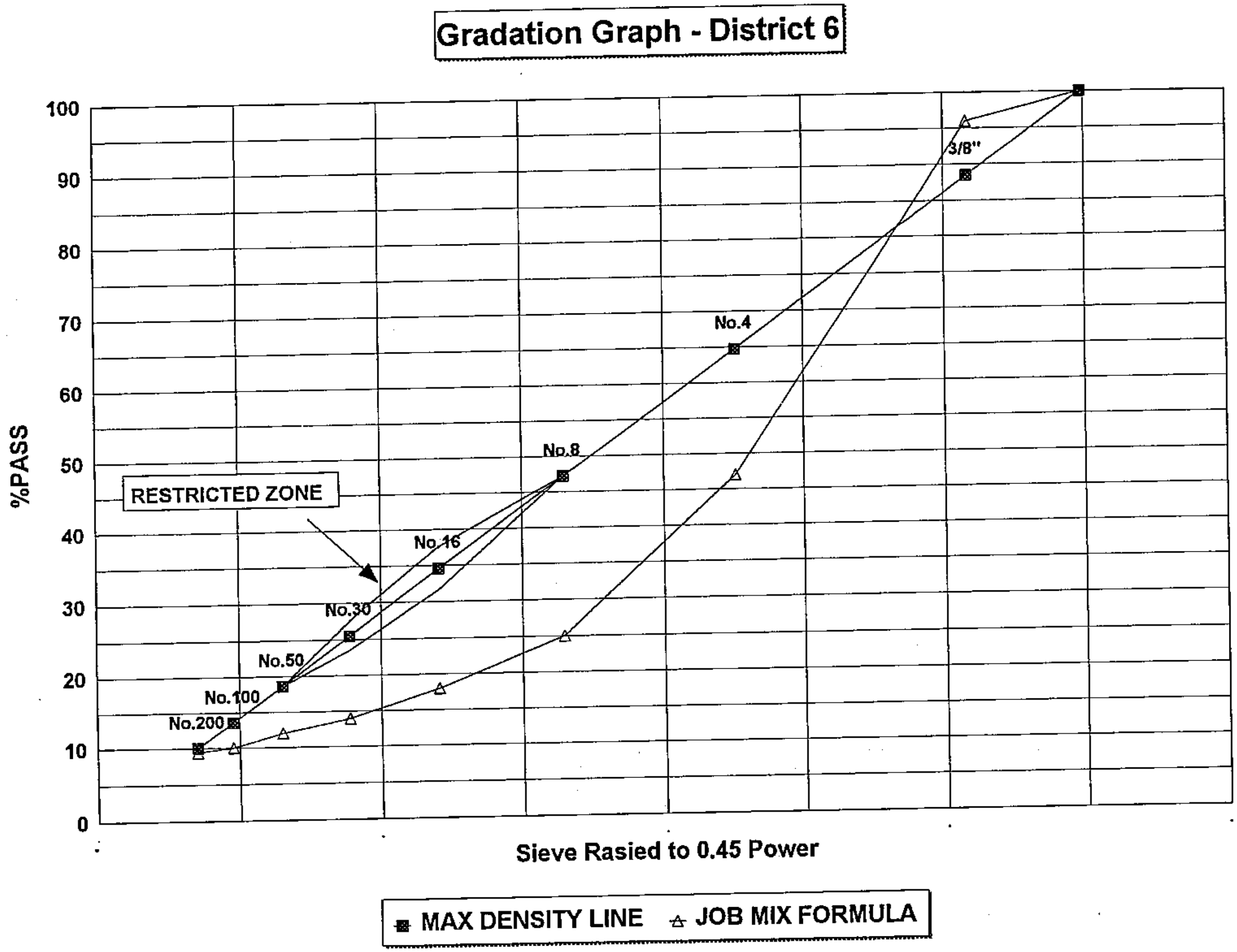
SUMMARY OF MARSHALL TEST DATA

| | A C %MIX | FLOW 1/100 | STABILITY POUNDS | MARSHALL SPEC GR | MAXIMUM SPEC GR | VOIDS TOT MIX | VMA | FILLED | EFFECT'V AC, VOL | AC, %WT | ABSORBTION WATER | AC | VOL AC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MIX 1 | 6.00 | 8.8 | 2146 | 2.354 | 2.474 | 4.83 | 15.98 | 69.8 | 11.15 | 4.91 | 3.91 | 2.47 | 13.62 |
| MIX 2 | 6.50 | 8.5 | 2182 | 2.380 | 2.458 | 3.16 | 15.51 | 79.6 | 12.35 | 5.38 | 3.94 | 2.57 | 14.92 |
| MIX 3 | 7.00 | 8.4 | 1948 | 2.377 | 2.440 | 2.57 | 16.07 | 84.0 | 13.50 | 5.89 | 3.91 | 2.55 | 16.05 |
| MIX 4 | 7.50 | 8.8 | 2059 | 2.389 | 2.424 | 1.44 | 16.11 | 91.1 | 14.66 | 6.37 | 3.91 | 2.61 | 17.28 |

| OPTIMUM DESIGN DATA: | % AC | STABILITY | FLOW | d | D | % VOIDS | VMA |
|---|---|---|---|---|---|---|---|
| | 6.4 | 2181 | 8.5 | 2.38 | 2.46 | 3.30 | 15.5 |

REMARKS: # 1125 ( SMA ) 50 - BLOW MARSHALL
THIS DESIGN DOES NOT MEET SPECIFICATIONS DUE A LOW (VMA) AND THE NUMBER 50 SIEVE ON THE FINAL BLEND.

J. G. Gehler, P.E.
Engineer of Materials and Physical Research




DATA TABLE

| | |
|---|---|
| No.200 | 9.4 |
| No.100 | 10 |
| No.50 | 12 |
| No.30 | 14 |
| No.16 | 18 |
| No.8 | 25 |
| No.4 | 47 |
| 3/8" | 96 |
| 1/2" | 100 |

VMA = 15.5

AGGREGATE SIZE

| | |
|---|---|
| CM16 | 69.6 |
| FM21 | 26.2 |
| MF02 | 3.9 |
| FIBER | 0.3 |

**APPENDIX C**

## PRELIMINARY TEST STRIP AND MODIFIED START-UP
## FOR
## STONE MATRIX ASPHALT (SMA)
## CRUMB RUBBER ASPHALT MIXTURES (RUMAC)

Effective April 5, 1993
Revised April 15, 1993

For projects containing SMA or RUMAC, a team shall be present at both a preliminary test strip and a modified start-up, for every SMA and RUMAC surface course and RUMAC binder course mixture.

A preliminary test strip shall be constructed for both SMA and RUMAC at a prescribed offsite area one week before the modified start-up to determine the mix properties, density, and laydown characteristics. These test results and visual inspections on the mixture shall be used to make corrective adjustments, if necessary.

A modified start-up shall be constructed for both SMA and RUMAC, on the job, at start of production of the mixtures. A nuclear/core correlation in accordance with the Department's "Standard Test Method For Correlating Nuclear Gauge Densities with Core Densities".

A. <u>Team Members</u>

The start-up team should consist of the following:

1. Resident Engineer
2. District Construction, Supervising Field Engineer, or Representative
3. District Materials, Mixtures Control Engineer, or Representative
4. District, Nuclear Density Gauge Specialist
5. Contractor's Representative
6. Bureau of Materials & Physical Research Representative
7. Bureau of Construction Representative

B. <u>Communications</u>

1. The Resident Engineer shall advise the team members of the anticipated start time of production for both the preliminary test strip and subsequent modified start-up for both the surface and binder courses.

2. A Department appointed representative shall direct the activities of the start-up team and act as spokesman in dealing with the Contractor during the progress of both the preliminary test-strip and modified start-up.

C. <u>Preliminary Test Strip</u>

The preliminary test strip shall consist of 300 tons. The first 200 tons shall contain 2 growth curves which shall be compacted by a vibratory roller (static mode for SMA) and tested as outlined herein. The remaining 100 tons is used to establish an acceptable rolling pattern.

1. Mix Information - The job mix formula will be approved and/or verified by the Department prior to preliminary test strip. On the day of construction of the preliminary test strip, the Contractor shall provide the start-up team documentation of test data showing the combined hot-bin or the combined aggregate belt sample and mineral filler at a drier-drum plant.

2. Mix and Gradation Test Strip Samples - The first set of mixture and gradation samples shall be taken by the Department at such a time as to represent the mixture in between the two growth curves constructed. The second series of mixture and gradation samples will be obtained from the last 100 tons placed during the start-up and after an acceptable rolling pattern has been established. All preliminary test strip samples shall be processed expediently by the Department for determination of mix composition and marshall properties including air voids. This shall include washed gradation tests. This information shall then be compared to the JMF and required design criteria.

3. Compaction Equipment - For RUMAC, the Contractor shall provide a vibratory roller meeting the requirements of Article 801.01(g) of the Standard Specifications. It shall be the responsibility of the start-up team to verify roller compliance before commencement of growth curve construction. An appropriate amplitude shall be selected on the basis of roller weight and mat thickness to achieve maximum density. If the vibratory roller does not meet the requirements of Article 801.01 (g), the laydown operation shall cease until a vibratory roller meeting the requirements is provided.

   For SMA, the Contractor shall provide two vibratory rollers meeting the requirements of Article 801.01 (g) of the Standard Specifications. These rollers shall be operated side by side in the static mode.

   All rolling equipment intended for use on either a RUMAC or SMA project shall be utilized on the preliminary test strip.

4. Constructing the Preliminary Test Strip - After the Contractor has produced, transported the mix in tarped trucks, and placed approximately 125 to 150 tons of mix, placement of mix shall stop and a growth curve shall be constructed. After completion of the first growth curve, paving shall resume for the remaining 50 to 75 tons and the second growth curve shall be constructed within this area. Paving shall stop until the second growth curve is completed and both growth curves evaluated.

   For the RUMAC, the Contractor shall use normal rolling procedures for all portions of the test strip except for the growth curve areas, which shall be compacted solely with a vibratory roller as directed by the Engineer. The vibratory roller speed shall be balanced with frequency so as to provide compaction at a rate of not less than 10 impacts per foot.

   For SMA, the Contractor shall use both rollers, side by side, in the static mode for all portions of the test strip, unless directed otherwise by the Department-appointed representative.

5. Location of Preliminary Test Strip - The preliminary test strip shall be located on a relatively flat portion of the roadway. Descending/ascending grades or ramps should be avoided.

6. Compaction Temperature - In order to make an accurate analysis of the density potential of the mixture, the temperature of the mixture on the pavement at the beginning of the growth curve shall not be less than 290° F. for SMA or 300° F. for RUMAC.

7. Compaction and Testing - The Engineer shall specify the roller(s) speed and number of passes required to obtain a completed growth curve. The nuclear gauge shall be placed near the center of the hot mat and the position marked for future reference. With the bottom of the nuclear gauge and source rod clean, a one (1) minute nuclear reading (without mineral filler) shall be taken after each pass of the roller. Rolling shall continue until the maximum density is achieved and three (3) consecutive passes show no appreciable increase in density or no evidence of destruction of the mat. The growth curve shall be plotted.

8. Final Testing - After the growth curve information is obtained, a final nuclear reading, using mineral filler to eliminate surface voids, will be taken at the marked position. This reading is used to adjust the maximum density reading obtained during the growth curve.

9. Evaluation of Growth Curves - Mixtures which exhibit density potential less than 93 percent or greater than 97 percent of the maximum theoretical density (D), shall be considered as sufficient cause for mix adjustment. If a mix adjustment is made, an additional Test Strip shall be constructed and associated tests shall be performed. This information shall then be compared to the AJMF and required design criteria.

   If the nuclear density potential of the mixture does not exceed 91% the operation will cease until all test data is analyzed or a new mix design is produced.

   In addition, other aspects of the mixture such as appearance, segregation, texture, or other evidence of mix problems should be noted and corrective action taken at this time.

D. Rolling Pattern

After completion of a satisfactory preliminary test strip, the Contractor shall establish a rolling pattern to achieve the required density specified.

E. Documentation

All preliminary test strip and rolling pattern information (including growth curves) shall be tabulated by a Department representative with copies provided each team member, and the original retained in the project files. Any changes to the rolling pattern shall be by the Contractor and the Engineer and recorded.

F. Modified Start-up

At the start of the SMA/RUMAC mixture placement, the Contractor shall construct a growth curve in between the first 125 and 150 tons for the purpose of evaluating the properties of the mixture, and ensuring that the rolling pattern established during the preliminary test strip was valid.

The mixing and placement shall stop until the growth curve has been evaluated. A hot-bin or a combined aggregate belt sample and a mix sample from the growth curve shall be obtained and tested expediently for determination of mix composition and marshall properties including air voids. This information shall then be compared to the preliminary test strip data.

If the growth curve and visual evaluation of the mix are satisfactory, the mixing and placement may be resumed. The rolling pattern established during the preliminary test strip shall be used. If the growth curve and visual evaluation of the mix are unsatisfactory, the Engineer will make appropriate adjustments and another test strip shall be constructed. This procedure will be followed until a satisfactory test strip is obtained.

The nuclear gauge to be used for quality control and/or quality acceptance shall be correlated with cores in accordance with Department procedures, noted previously. All correlation locations shall be cooled with ice or dry ice so that cores can be obtained as soon as possible. Smoothness requirements will be to the satisfaction of the Engineer.

## APPENDIX D

BDESIGNW
VERSION 1.3

IDOT - Bureau of Materials and Physical Research
Bituminous Mixture Design

DATE: 01-Sep-93

SEQ NO:

Design Number: 52BIT1427

Mixture Producer: MCCARTHY IMPROVEMENTS ( 1181-02 )
Mixture: 1843201 BITCONC SCS 2 D MA )

| | #1 | #2 | #3 | #4 | #5 | #6 | ASPHALT |
|---|---|---|---|---|---|---|---|
| Agg No. | #1 | #2 | #3 | #4 | #5 | #6 | ASPHALT |
| Size | 032CA13 | 038FA20 | 43499 | 004MF01 | | | 10112 |
| Source (PROD#) | 50732-12 | 50732-12 | 5028-01 | 52202-08 | | | 94-02 |
| (NAME) | MOLINE | MOLINE | CENTRAL | LINWOOD | | | AMOCO |
| (LOC) | CONS. | CONS. | FIBERS | | | | OIL |
| Aggregate Blend | 74.1 | 17.0 | 0.3 | 8.6 | | | 100.0 |

| Agg No. / Sieve Size | #1 | #2 | #3 | #4 | #5 | #6 | Blend | Specifications Min | Max | FORMULA | FORMULA RANGE Min | Max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | --- | --- | 100 | | |
| 3/4 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100 | 100 | 100 | | |
| 1/2 | 98.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 98.5 | 100 | 100 | 99 | | |
| 3/8 | 74.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 80.7 | 90 | 100 | 81 | | |
| #4 | 16.0 | 98.0 | 100.0 | 100.0 | 100.0 | 100.0 | 37.4 | 28 | 50 | 37 | | |
| #8 | 5.0 | 81.4 | 100.0 | 100.0 | 100.0 | 100.0 | 26.4 | 21 | 28 | 26 | | |
| #16 | 2.0 | 43.1 | 100.0 | 100.0 | 100.0 | 100.0 | 17.7 | | | 18 | | |
| #30 | 1.0 | 22.3 | 77.0 | 100.0 | 100.0 | 100.0 | 13.4 | 12 | 16 | 13 | | |
| #50 | 1.0 | 12.6 | 57.0 | 100.0 | 100.0 | 100.0 | 11.7 | 12 | 15 | 12 | | |
| #100 | 1.0 | 8.4 | 5.0 | 98.0 | 100.0 | 100.0 | 10.6 | | | 11 | | |
| #200 | 0.3 | 5.5 | 20.0 | 93.2 | 100.0 | 100.0 | 9.2 | 8 | 10 | 9.2 | | |

| | #1 | #2 | #3 | #4 | #5 | #6 | |
|---|---|---|---|---|---|---|---|
| Bulk Sp Gr | 2.7 | 2.741 | 1.13 | 2.74 | 1 | 1 | |
| Apparent Sp Gr | 2.784 | 2.79 | 1.13 | 2.74 | 1 | 1 | |
| Absorption, % | 1.1 | 0.6 | 0 | 0 | 0 | 0 | |
| | | | | | | SP GR AC | 1.032 |

SUMMARY OF MARSHALL TEST DATA

| | A C %MIX | FLOW 1/100 | STABILITY POUNDS | MARSHALL SPEC GR | MAXIMUM SPEC GR | VOIDS TOT MIX | VMA | FILLED | EFFECT'V AC, VOL | AC, %WT | ABSORBTION WATER | AC | VOL AC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MIX 1 | 6.00 | 9.7 | 2067 | 2.443 | 2.495 | 2.10 | 14.93 | 85.9 | 12.83 | 5.42 | 2.15 | 1.37 | 14.20 |
| MIX 2 | 6.50 | 10.8 | 1970 | 2.443 | 2.479 | 1.45 | 15.36 | 90.6 | 13.92 | 5.88 | 2.14 | 1.47 | 15.39 |
| MIX 3 | 7.00 | 11.8 | 1951 | 2.443 | 2.461 | 0.72 | 15.81 | 95.5 | 15.09 | 6.37 | 2.13 | 1.48 | 16.57 |
| MIX 4 | 7.50 | 15.7 | 1782 | 2.435 | 2.445 | 0.39 | 16.53 | 97.6 | 16.14 | 6.84 | 2.11 | 1.56 | 17.70 |

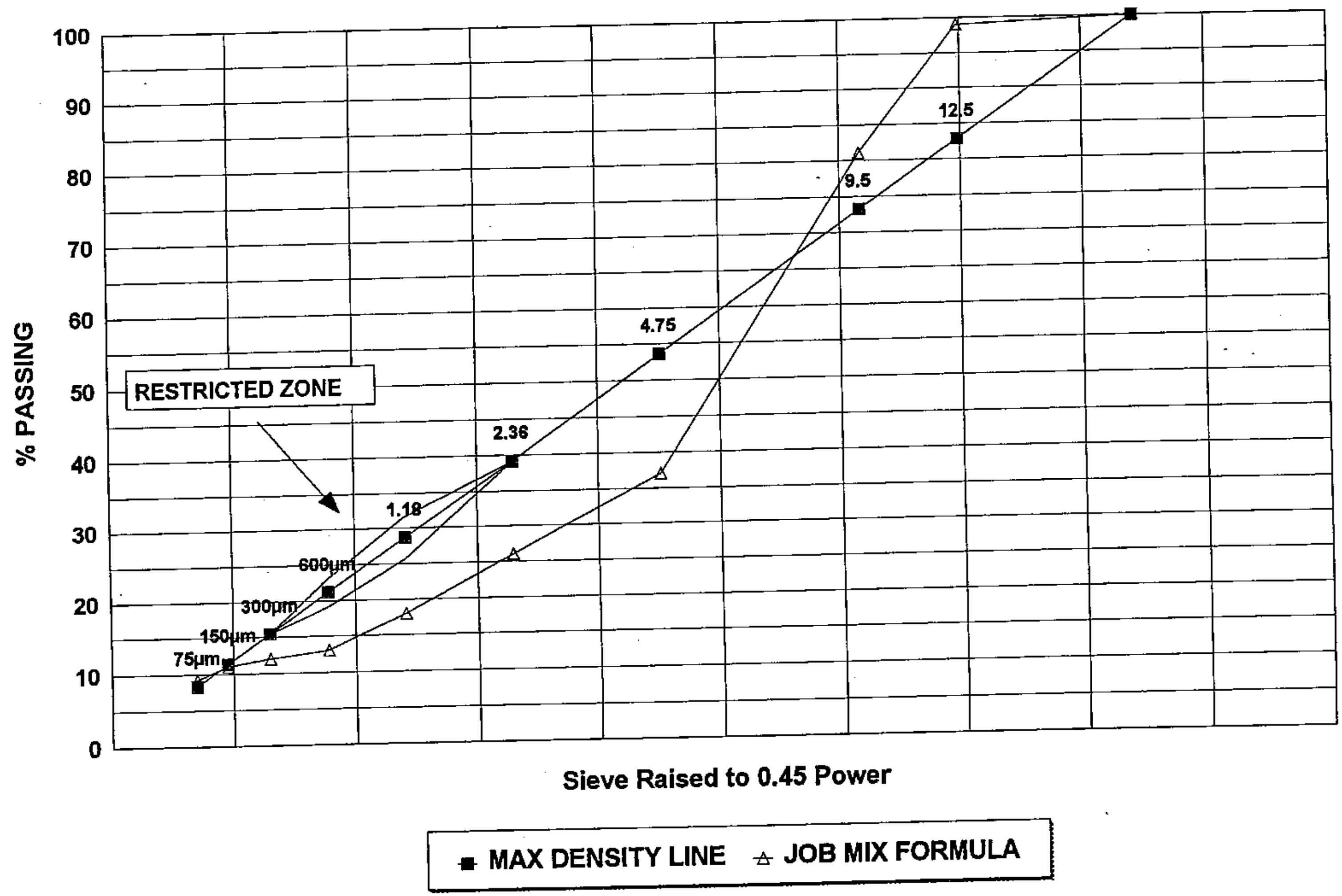
OPTIMUM DESIGN DATA:

| % AC | STABILITY | FLOW | d | D | % VOIDS | VMA |
|---|---|---|---|---|---|---|
| 6.0 | 2067 | 9.7 | 2.44 | 2.50 | 2.1 | 14.9 |

REMARKS: # 1126 - 50 BLOW MARSHALL. THIS DESIGN DOES NOT MEET THE SPECIFICATIONS FOR VMA,VOIDS, 1/2 IN. AND 3/8 IN. SIEVE.

J. G. Gehler, P.E.
Engineer of Materials and Physical Research

## Gradation Graph - District 2




DATA TABLE

| | |
|---|---|
| 75µm | 9.2 |
| 150µm | 11 |
| 300µm | 12 |
| 600µm | 13 |
| 1.18 | 18 |
| 2.36 | 26 |
| 4.75 | 37 |
| 9.5 | 81 |
| 12.5 | 99 |
| 19 | 100 |

VMA = 14.9

AGGREGATE SIZE

| | |
|---|---|
| CM13 | 74.1 |
| FA20 | 17 |
| MF01 | 8.6 |
| FIBER | 0.3 |

## APPENDIX E

BDESIGNW
VERSION 1.5

IDOT - Bureau of Materials and Physical Research
Bituminous Mixture Design

DATE: 06-Apr-94

SEQ NO:

Design Number: 51BIT0000

Mixture Producer: GALLAGHER (716-03)
Mixture: 1843101

| Agg No. | #1 | #2 | #3 | #4 | #5 | #6 | ASPHALT |
|---|---|---|---|---|---|---|---|
| Size | 032CM00 | 032CM16 | 038FM20 | 004MF01 | 004MF02 | 43495 | 10112 |
| Source (PROD#) | MATSERV | MATSERV | MATSERV | MATSERV | GLLGR | CENTFBR | AMOCO |
| (NAME) | 50312-04 | 50312-04 | 50312-04 | 50312-04 | 716-03 | 5028-01 | 94-04 |
| (LOC) | | | | | | | |
| Aggregate Blend | 29.8 | 49.7 | 12.1 | 8.1 | | 0.3 | 100.0 |

| Agg No. Sieve Size | #1 | #2 | #3 | #4 | #5 | #6 | Blend | Specifications Min | Max | FORMULA | FORMULA RANGE Min | Max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | 100 | | |
| 1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100 | 100 | 100 | | |
| 3/4 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 85 | 95 | 87 | | |
| 1/2 | 57.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 87.2 | 60 | 75 | 70 | | |
| 3/8 | 6.0 | 95.0 | 100.0 | 100.0 | 100.0 | 100.0 | 69.5 | 25 | 32 | 29 | | |
| #4 | 2.0 | 16.0 | 100.0 | 100.0 | 100.0 | 100.0 | 29.0 | 18 | 24 | 22 | | |
| #8 | 2.0 | 2.0 | 96.7 | 100.0 | 100.0 | 100.0 | 21.7 | | | 16 | | |
| #16 | 1.0 | 1.0 | 60.0 | 100.0 | 100.0 | 100.0 | 16.5 | 12 | 16 | 13 | | |
| #30 | 1.0 | 1.0 | 32.7 | 100.0 | 100.0 | 77.0 | 13.1 | 12 | 15 | 11 | OUT | |
| #50 | 1.0 | 1.0 | 15.6 | 100.0 | 100.0 | 57.0 | 11.0 | | | 10 | | |
| #100 | 1.0 | 1.0 | 5.3 | 99.0 | 100.0 | 39.0 | 9.6 | 8 | 10 | 8.1 | | |
| #200 | 0.9 | 0.6 | 1.9 | 89.1 | 97.4 | 20.0 | 8.1 | | | | | |

| | #1 | #2 | #3 | #4 | #5 | #6 | |
|---|---|---|---|---|---|---|---|
| Bulk Sp Gr | 2.639 | 2.667 | 2.717 | 2.823 | 2.742 | 1.13 | |
| Apparent Sp Gr | 2.755 | 2.78 | 2.788 | 2.823 | 2.742 | 1.13 | |
| Absorption, % | 1.6 | 1.5 | 0.9 | 0 | 0 | 0 | |
| | | | | | | SP GR AC | 1.039 |

SUMMARY OF MARSHALL TEST DATA

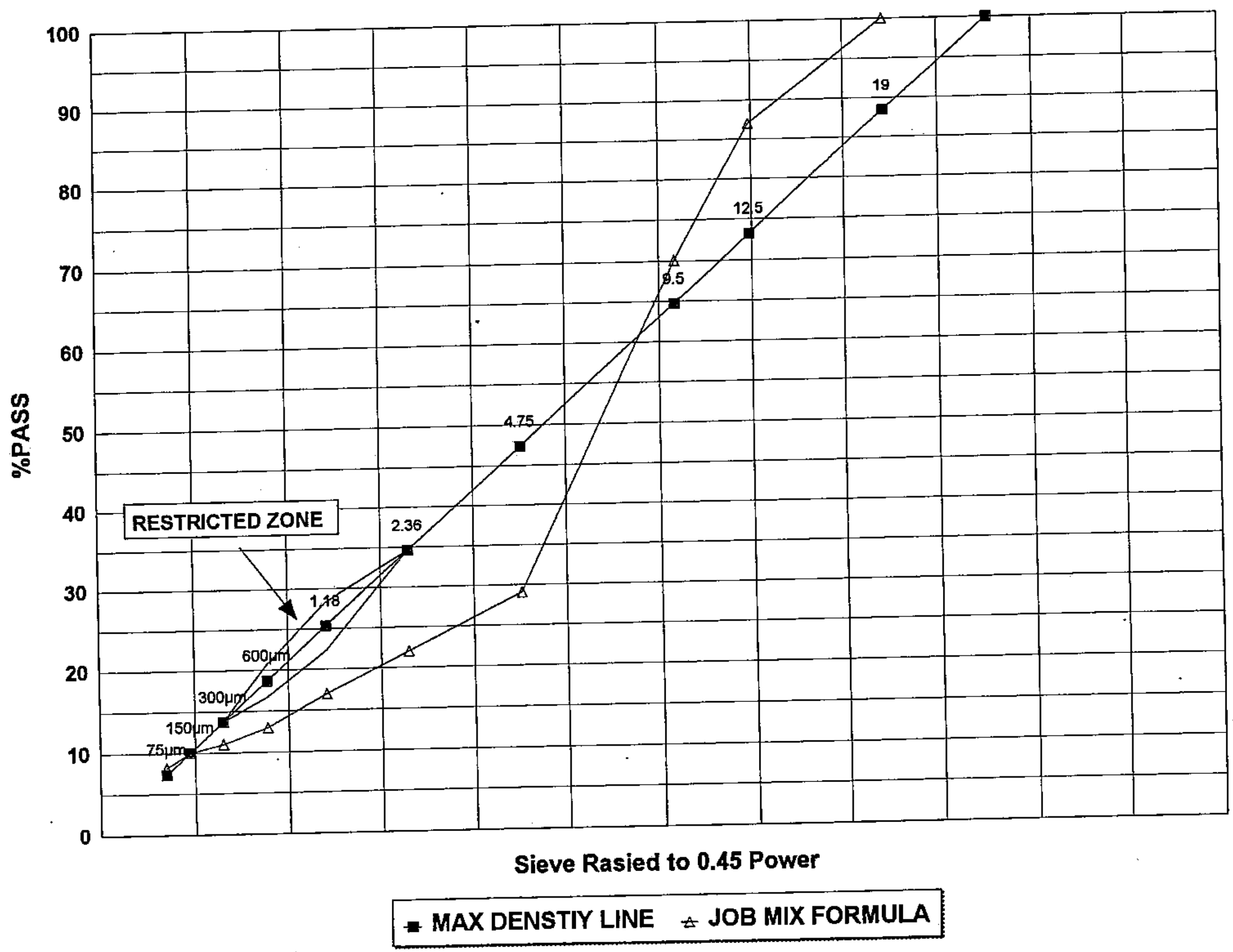
| | A C %MIX | FLOW 1/100 | STABILITY POUNDS | MARSHALL SPEC GR | MAXIMUM SPEC GR | VOIDS TOT MIX | VMA | FILLED | EFFECT'V AC, VOL | AC, %WT | ABSORBTION WATER | AC | VOL AC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MIX 1 | 6.00 | 9.7 | 1872 | 2.391 | 2.493 | 4.08 | 15.67 | 74.0 | 11.59 | 5.04 | 3.03 | 2.22 | 13.81 |
| MIX 2 | 6.50 | 9.3 | 1872 | 2.401 | 2.469 | 2.74 | 15.77 | 82.6 | 13.03 | 5.64 | 3.02 | 1.99 | 15.02 |
| MIX 3 | 7.00 | 8.7 | 1866 | 2.398 | 2.450 | 2.12 | 16.33 | 87.0 | 14.21 | 6.16 | 3.00 | 1.94 | 16.16 |
| MIX 4 | 7.50 | 11.0 | 1943 | 2.396 | 2.432 | 1.50 | 16.87 | 91.1 | 15.37 | 6.67 | 2.98 | 1.92 | 17.29 |

| OPTIMUM DESIGN DATA: | % AC | STABILITY | FLOW | d | D | % VOIDS | VMA |
|---|---|---|---|---|---|---|---|
| | 6.2 | 1872 | 9.4 | 2.40 | 2.49 | 3.5 | 15.7 |

REMARKS: 50 - BLOW MARSHALL. ( STONE MATRIX ASPHALT )

J. G. Gehler, P.E.
Engineer of Materials and Physical Research

## Gradation Graph - District 1




DATA TABLE

| | |
|---|---|
| 75µm | 8.1 |
| 150µm | 10 |
| 300µm | 11 |
| 600µm | 13 |
| 1.18 | 17 |
| 2.36 | 22 |
| 4.75 | 29 |
| 9.5 | 70 |
| 12.5 | 87 |
| 19 | 100 |
| 25 | 100 |

VMA = 15.7

AGGREGATE SIZE

| | |
|---|---|
| CM00 | 29.8 |
| CM13 | |
| CM16 | 49.7 |
| FA20 | 12.1 |
| MF01 | 8.1 |
| FIBER | 0.3 |

# APPENDIX F

BDESIGNW
VERSION 1.4

IDOT - Bureau of Materials and Physical Research
Bituminous Mixture Design

DATE: 11-Jul-94

SEQ NO:

Design Number: 53BIT1336

Mixture Producer: AZZARELLI (154-13)
Mixture: 18433

| Agg No. | #1 | #2 | #3 | #4 | #5 | #6 | ASPHALT |
|---|---|---|---|---|---|---|---|
| Size | 032CM00 | 032CM16 | 038FA20 | 004MF01 | | | |
| Source (PROD#) | 52102-01 | 50912-02 | 50912-02 | 50312-04 | | | 604-05 |
| (NAME) | NEWTON | VULCAN | VULCAN | MAT SERV | | | KOCH |
| (LOC) | | | | | | | |
| Aggregate Blend | 25.5 | 55.0 | 11.0 | 8.5 | | | 100.0 |

| Agg No. / Sieve Size | #1 | #2 | #3 | #4 | #5 | #6 | Blend | Specifications Min | Max | FORMULA | FORMULA RANGE Min | Max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100 | | 100 | | |
| 3/4 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100 | | 100 | | |
| 1/2 | 66.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 91.3 | 85 | 95 | 91 | | |
| 3/8 | 4.0 | 96.0 | 100.0 | 100.0 | 100.0 | 100.0 | 73.3 | 60 | 75 | 73 | | |
| #4 | 2.0 | 22.0 | 98.0 | 100.0 | 100.0 | 100.0 | 31.9 | 25 | 32 | 32 | | |
| #8 | 2.0 | 8.0 | 73.0 | 100.0 | 100.0 | 100.0 | 21.4 | 18 | 24 | 21 | | |
| #16 | 2.0 | 3.8 | 42.0 | 100.0 | 100.0 | 100.0 | 15.7 | | | 16 | | |
| #30 | 2.0 | 3.0 | 24.0 | 100.0 | 100.0 | 100.0 | 13.3 | 12 | 16 | 13 | | |
| #50 | 2.0 | 2.6 | 12.0 | 100.0 | 100.0 | 100.0 | 11.8 | 12 | 15 | 12 | | |
| #100 | 1.3 | 2.4 | 6.6 | 99.3 | 100.0 | 100.0 | 10.8 | | | 11 | | |
| #200 | 0.8 | 2.2 | 4.6 | 90.4 | 100.0 | 100.0 | 9.6 | 8 | 10 | 9.6 | | |

| | #1 | #2 | #3 | #4 | #5 | #6 | |
|---|---|---|---|---|---|---|---|
| Bulk Sp Gr | 2.621 | 2.631 | 2.703 | 2.81 | 1 | 1 | |
| Apparent Sp Gr | 2.764 | 2.778 | 2.782 | 2.81 | 1 | 1 | |
| Absorption, % | 1.1 | 2 | 2 | 0 | 0 | 0 | |
| | | | | | | SP GR AC | 1.03 |

SUMMARY OF MARSHALL TEST DATA

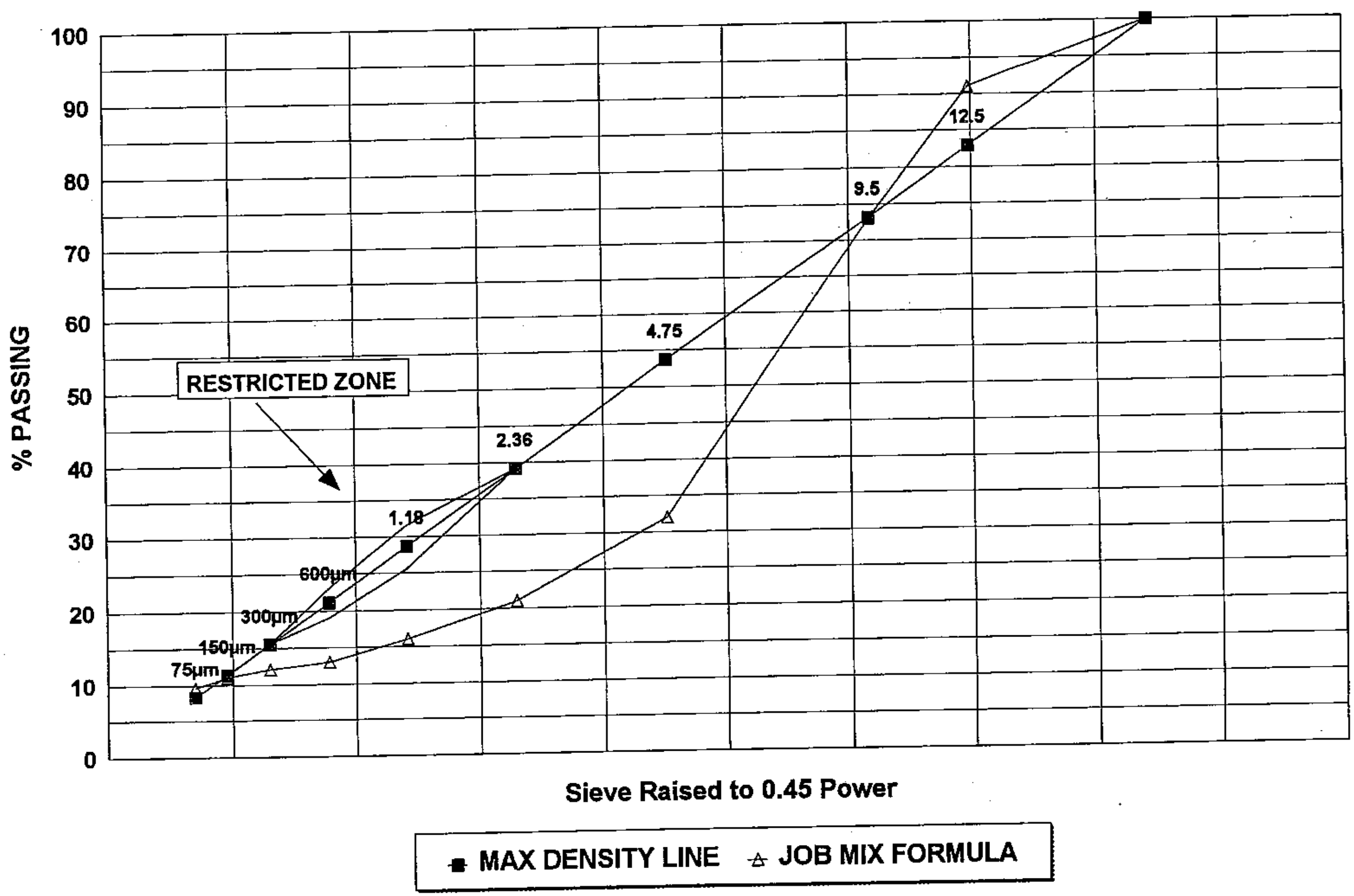
| | A C %MIX | FLOW 1/100 | STABILITY POUNDS | MARSHALL SPEC GR (Gmb) | MAXIMUM SPEC GR (Gmm) | VOIDS TOT MIX (Pa) | VMA | VOID FILLED | EFFECTIVE AC, VOL | EFFECTIVE AC, %WT | Gse | ABSORBTION AC, %WT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MIX 1 | 6.00 | 12.3 | 1896 | 2.364 | 2.464 | 4.05 | 16.16 | 74.9 | 12.10 | 5.27 | 2.704 | 0.77 |
| MIX 2 | 6.50 | 12.9 | 2011 | 2.382 | 2.450 | 2.79 | 15.99 | 82.5 | 13.19 | 5.71 | 2.710 | 0.85 |
| MIX 3 | 7.00 | 13.8 | 1961 | 2.382 | 2.432 | 2.04 | 16.41 | 87.6 | 14.37 | 6.21 | 2.710 | 0.85 |
| MIX 4 | 7.50 | 11.7 | 1892 | 2.375 | 2.419 | 1.83 | 17.12 | 89.3 | 15.30 | 6.63 | 2.716 | 0.94 |

| OPTIMUM DESIGN DATA: | % AC | STABILITY | FLOW | d (Gmb) | D (Gmm) | % VOIDS (Pa) | VMA | VFA |
|---|---|---|---|---|---|---|---|---|
| | 6.3 | 1965 | 12.7 | 2.375 | 2.456 | 3.3 | 16.1 | 79.5 |

REMARKS: DESIGN # 1150B 50 BLOW MARSHALL
VMA BELOW MINIMUM SPECIFICATION
THE SCHELLENBERG DRAINDOWN TEST FAILED (2.29%).

J. G. Gehler, P.E.
Engineer of Materials and Physical Research

# Gradation Graph - District 3




DATA TABLE

| | |
|---|---|
| 75µm | 9.6 |
| 150µm | 11 |
| 300µm | 12 |
| 600µm | 13 |
| 1.18 | 16 |
| 2.36 | 21 |
| 4.75 | 32 |
| 9.5 | 73 |
| 12.5 | 91 |
| 19 | 100 |

VMA = 16.1

AGGREGATE SIZE

| | |
|---|---|
| CM00 | 25.5 |
| CM13 | |
| CM16 | 55 |
| FA20 | 11 |
| MF01 | 8.5 |

**APPENDIX G**

BDESIGNW IDOT - Bureau of Materials and Physical Research DATE: 24-Jun-94
VERSION 1.4 Bituminous Mixture Design

SEQ NO:

Design Number: 58IT1380

Mixture Producer: MACLAIR ASPHALT (1202-04)
Mixture: 1843101

| Agg No. | #1 | #2 | #3 | #4 | #5 | #6 | ASPHALT |
|---|---|---|---|---|---|---|---|
| Size | 032CM00 | 032CM13 | 038FA20 | 004MF01 | 43496 | | 10112 |
| Source (PROD#) | 52302-33 | 52302-33 | 52302-53 | 52302-08 | | | 575-01 |
| (NAME) | IRON MT | IRON MT | FT BELL | MISS LIME | FIBERAND | | APEX |
| (LOC) | | | | | | | |
| Aggregate Blend | 32.5 | 48.8 | 9.0 | 9.0 | 0.7 | | 100.0 |

| Agg No. Sieve Size | #1 | #2 | #3 | #4 | #5 | #6 | Blend | Specifications Min | Max | FORMULA | FORMULA RANGE Min | Max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | | | 100 | | |
| 3/4 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100 | 100 | 100 | | |
| 1/2 | 60.2 | 97.0 | 100.0 | 100.0 | 100.0 | 100.0 | 85.6 | 85 | 95 | 86 | | |
| 3/8 | 6.0 | 75.0 | 100.0 | 100.0 | 100.0 | 100.0 | 57.3 | 60 | 75 | 57 | OUT | |
| #4 | 0.9 | 21.0 | 100.0 | 100.0 | 100.0 | 100.0 | 29.2 | 25 | 32 | 29 | | |
| #8 | 0.6 | 2.0 | 80.0 | 100.0 | 100.0 | 100.0 | 18.1 | 18 | 24 | 18 | | |
| #16 | 0.4 | 0.0 | 45.0 | 100.0 | 100.0 | 100.0 | 13.9 | | | 14 | | |
| #30 | 0.3 | 0.0 | 25.0 | 100.0 | 100.0 | 100.0 | 12.0 | 12 | 16 | 12 | | |
| #50 | 0.2 | 0.0 | 13.0 | 100.0 | 96.0 | 100.0 | 10.9 | 12 | 15 | 11 | OUT | |
| #100 | 0.1 | 0.0 | 6.0 | 95.0 | 91.0 | 100.0 | 9.8 | | | 10 | | |
| #200 | 0.0 | 0.0 | 4.3 | 85.3 | 86.0 | 100.0 | 8.7 | 8 | 10 | 8.7 | | |

| | #1 | #2 | #3 | #4 | #5 | #6 | |
|---|---|---|---|---|---|---|---|
| Bulk Sp Gr | 2.642 | 2.623 | 2.528 | 2.73 | 2.85 | 1 | |
| Apparent Sp Gr | 2.659 | 2.646 | 2.706 | 2.73 | 2.85 | 1 | |
| Absorption, % | 0.2 | 0.3 | 2.6 | 0 | 0 | 0 | |
| | | | | | | SP GR AC | 1.029 |

SUMMARY OF MARSHALL TEST DATA

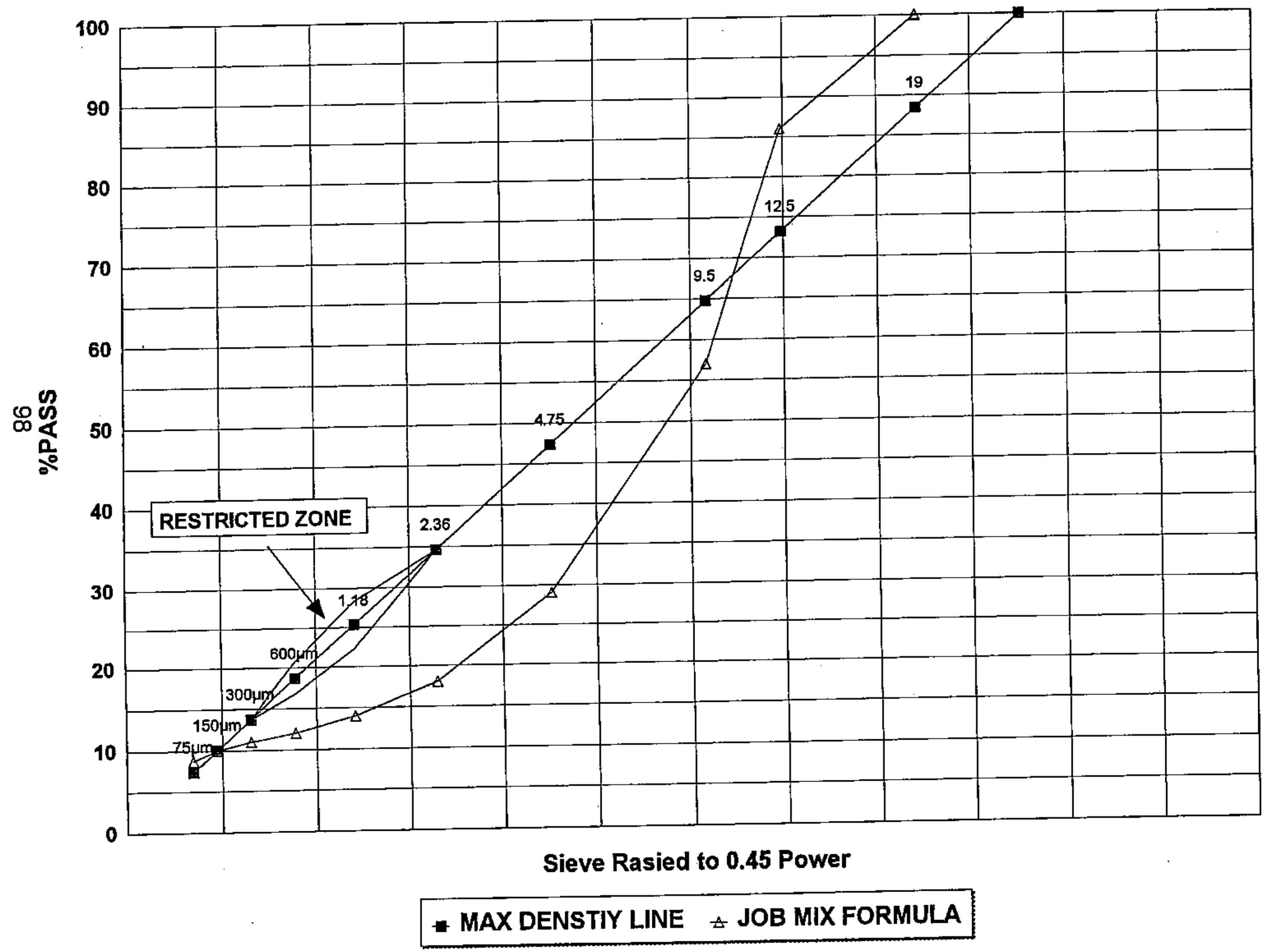
| | A C %MIX | FLOW 1/100 | STABILITY POUNDS | MARSHALL SPEC GR (Gmb) | MAXIMUM SPEC GR (Gmm) | VOIDS TOT MIX (Pa) | VMA | VOID FILLED | EFFECTIVE AC, VOL | EFFECTIVE AC, %WT | Gse | ABSORBTION AC, %WT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MIX 1 | 6.00 | 10.5 | 951 | 2.282 | 2.441 | 6.51 | 18.46 | 64.8 | 11.96 | 5.39 | 2.675 | 0.65 |
| MIX 2 | 6.50 | 11.2 | 1122 | 2.303 | 2.425 | 5.01 | 18.14 | 72.4 | 13.13 | 5.86 | 2.678 | 0.68 |
| MIX 3 | 7.00 | 12.7 | 1156 | 2.305 | 2.404 | 4.11 | 18.52 | 77.8 | 14.41 | 6.43 | 2.673 | 0.61 |
| MIX 4 | 7.50 | 14.0 | 1029 | 2.300 | 2.387 | 3.63 | 19.12 | 81.0 | 15.50 | 6.93 | 2.673 | 0.61 |

| TIMUM DESIGN DATA: | % AC | STABILITY | FLOW | d (Gmb) | D (Gmm) | % VOIDS (Pa) | VMA | VFA |
|---|---|---|---|---|---|---|---|---|
| | 7.0 | 1156 | 12.7 | 2.305 | 2.404 | 4.11 | 18.52 | 77.8 |

MARKS: DESIGN # 1153 50 BLOW MARSHALL
AGG BLEND ON 3/8" & #50 SIEVES AND STABILITY OUT OF SPECIFICATION
SCHELLENBURG DRAIN-DOWN TEST RESULT = 0.267

J. G. Gehler, P.E.
Engineer of Materials and Physical Research

## Gradation Graph - District 8




DATA TABLE

| | |
|---|---|
| 75µm | 8.7 |
| 150µm | 10 |
| 300µm | 11 |
| 600µm | 12 |
| 1.18 | 14 |
| 2.36 | 18 |
| 4.75 | 29 |
| 9.5 | 57 |
| 12.5 | 86 |
| 19 | 100 |
| 25 | 100 |

VMA = 18.5

AGGREGATE SIZE

| | |
|---|---|
| CM00 | 32.5 |
| CM13 | 48.8 |
| CM16 | |
| FA20 | 9.0 |
| MF01 | 9.0 |
| FIBER | 0.7 |

## APPENDIX H

BDESIGNW IDOT - District 1 Bureau of Materials DATE: 18-Oct-94 VERSION 91.010

Bituminous Mixture Design

GROUP: H

Design Number: 31BIT04~~28~~ 52

Agg Source: LEVY BRNS HRB 52103-10

Mixture: 18434 BIT SMA .50IN POLY

| Bin # | #4 | #3 | #2 | #1 | MF | RAP | ASPHALT |
|---|---|---|---|---|---|---|---|
| Size | | 039CM00 | | 038FA20 | 004MF01 | | 10112 |
| Source (NAME) | | LEVY | | MS | MS | | SENECA |
| (LOC) | | BRNS HRB | | THORNTN | THORNTN | | LEMONT |
| (PROD#) | | 52103-10 | | 50312-04 | 50312-04 | | 1737-05 |
| Aggregate Blend | | 82.0 | | 13.5 | 4.5 | | 100.0 |

| Bin # | #4 | #3 | #2 | #1 | MF | RAP | Blend | Specifications Min | Max | FORMULA | FORMULA RANGE Min | Max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sieve Size | | | | | | | | | | | | |
| 1 | | 100.0 | | 100.0 | 100.0 | | 100.0 | | | 100 | --- | --- |
| 3/4 | | 100.0 | | 100.0 | 100.0 | | 100.0 | | | 100 | 100 | 100 |
| 1/2 | | 82.1 | | 100.0 | 100.0 | | 85.3 | | | 85 | 85 | 85 |
| 3/8 | | 46.9 | | 100.0 | 100.0 | | 56.5 | | | 56 | --- | --- |
| #4 | | 6.0 | | 100.0 | 100.0 | | 22.9 | | | 23 | 18 | 28 |
| #8 | | 3.1 | | 96.0 | 100.0 | | 20.0 | | | 20 | 16 | 24 |
| #16 | | 2.9 | | 61.8 | 100.0 | | 15.2 | | | 15 | 11 | 19 |
| #30 | | 2.7 | | 34.0 | 100.0 | | 11.3 | | | 11 | --- | --- |
| #50 | | 2.6 | | 15.3 | 100.0 | | 8.7 | | | 9 | 6 | 12 |
| #100 | | 2.4 | | 5.4 | 97.2 | | 7.1 | | | 7 | --- | --- |
| #200 | | 2.0 | | 2.7 | 81.0 | | 5.6 | | | 5.6 | 4.0 | 7.2 |

| | #4 | #3 | #2 | #1 | MF | RAP | |
|---|---|---|---|---|---|---|---|
| Bulk Sp Gr | 1.000 | 3.260 | 1.000 | 2.725 | 2.824 | 1.000 | |
| Apparent Sp Gr | 1.000 | 3.472 | 1.000 | 2.831 | 2.824 | 1.000 | |
| Absorption, % | 0.0 | 1.9 | 0.0 | 1.4 | 0.0 | 0.0 | |
| | | | | | | SP GR AC | 1.032 |

SUMMARY OF MARSHALL TEST DATA

| | A C %MIX | FLOW 1/100 | STAB. POUNDS | BULK SPEC GR | MAX SPEC GR | VOIDS TOT MIX | VMA | VFA | EFFECT'V AC, VOL | ABSORBTION AC, %WT | WATER | AC | VOL AC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MIX 1 | 5.00 | 10.8 | 2184 | 2.823 | 2.953 | 4.40 | 14.99 | 70.6 | 10.58 | 3.87 | 4.62 | 3.10 | 13.68 |
| MIX 2 | 5.50 | 12.4 | 2158 | 2.811 | 2.935 | 4.22 | 15.79 | 73.2 | 11.56 | 4.25 | 4.57 | 3.42 | 14.98 |
| MIX 3 | 6.00 | 13.6 | 1799 | 2.808 | 2.908 | 3.43 | 16.32 | 79.0 | 12.89 | 4.74 | 4.54 | 3.44 | 16.33 |
| MIX 4 | 6.50 | 10.6 | 1997 | 2.803 | 2.895 | 3.17 | 16.91 | 81.2 | 13.74 | 5.06 | 4.51 | 3.91 | 17.66 |

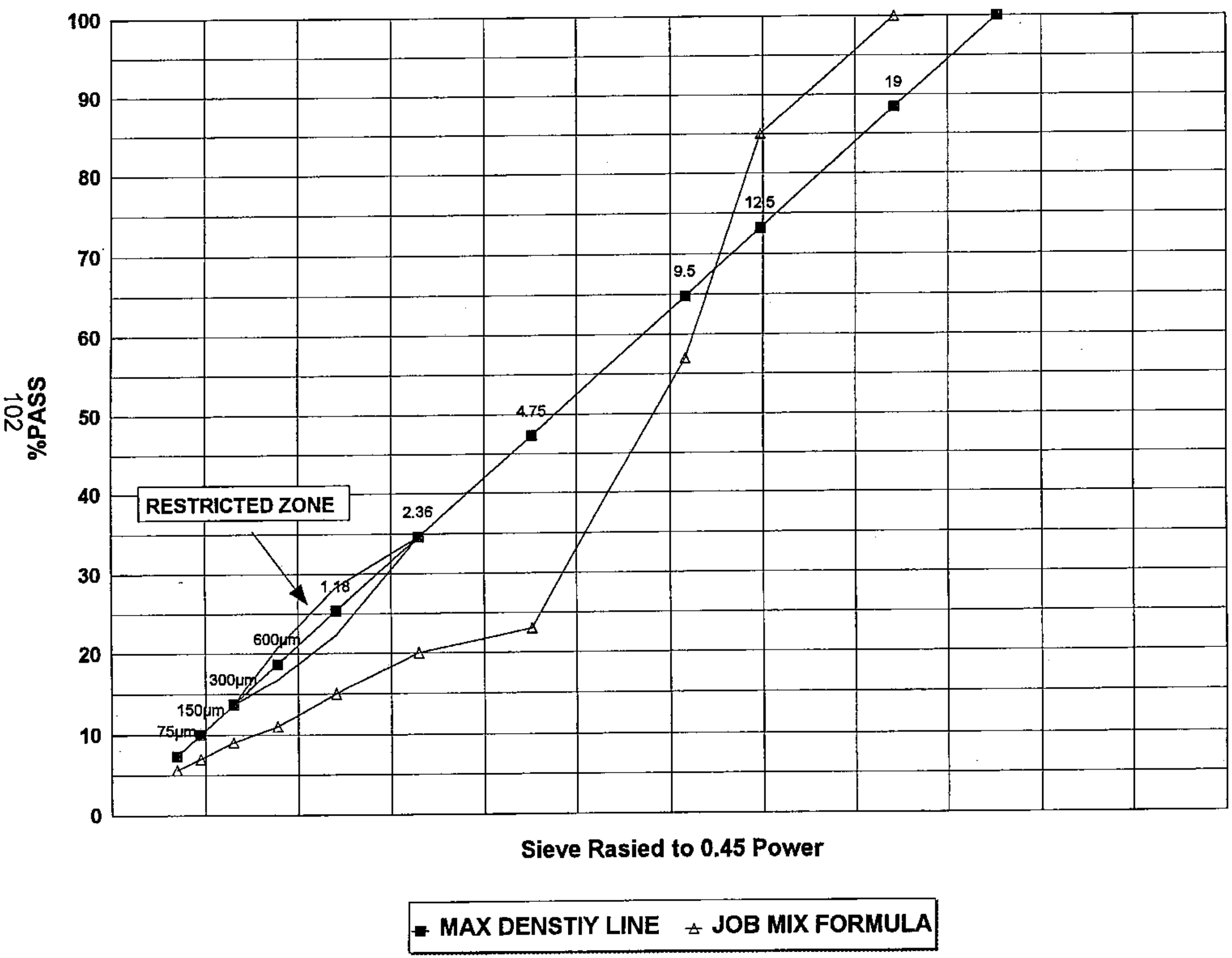
| OPTIMUM DATA: | % AC | FLOW | STABILITY | d | D | % VOIDS | VMA | VFA | TSR | ADD/TSR | BLOWS | RAP AC % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AC-20 | 6.0 | 13.8 | 1800 | 2.81 | 2.91 | 3.5 | 16.3 | 79.0 | | * | 75 | |
| MAC-20 | 6.0 | 15.5 | 2176 | 2.83 | 2.88 | 2.0 | 15.7 | 87.2 | | 1.07 | 75 | |

REMARKS: ANTISTRIP: 1.0 % PAVEBOND

* TEST NOT POSSIBLE DUE TO LACK OF ADHESION IN CONDITIONED SPECIMENS

BRUCE DINKHELLER
District Engineer of Materials

## Gradation Graph - District 1, Steel Slag




**DATA TABLE**

| | |
|---|---|
| 75µm | 5.6 |
| 150µm | 7 |
| 300µm | 9 |
| 600µm | 11 |
| 1.18 | 15 |
| 2.36 | 20 |
| 4.75 | 23 |
| 9.5 | 57 |
| 12.5 | 85 |
| 19 | 100 |
| 25 | 100 |

VMA = 16.3

**AGGREGATE SIZE**

| | |
|---|---|
| CM00 | 82.0 |
| CM13 | |
| CM16 | |
| FM20 | 13.5 |
| MF01 | 4.5 |